Accompanies Episode 1 of the 13-part video series

Perilous Plankton

Written by Eric R Russell & Bruce J Russell

In this episode...

Cyclops and its intrepid crew of explorers dive into the pond's open water where they get an uncomfortably close view of a filter feeding copepod, barely escaping its powerful feeding currents. They next have a lyrical encounter with *Volvox*, a beautiful colonial alga, and survive a collision with *Daphnia* the water flea, leading to unique views of an animal's internal organs in action and its special adaptations for living in suspension.

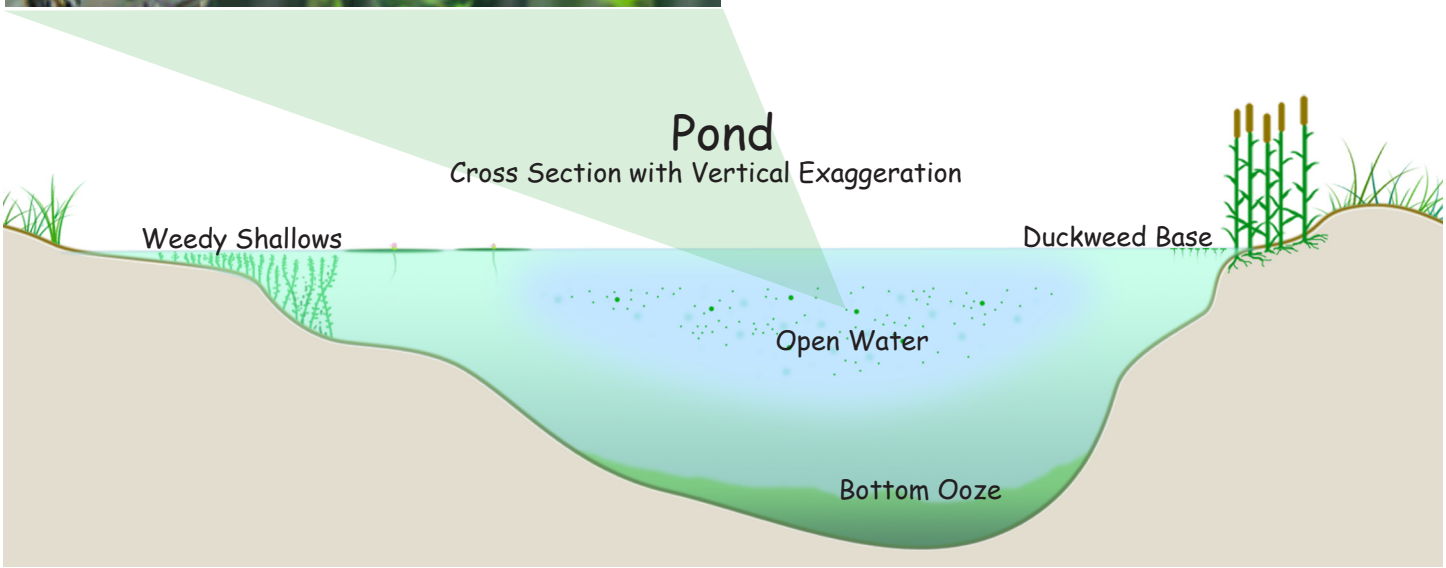
Pond Ecology: Open Water

The Log of Captain Jonathan Adler

Day 1: 06:30 hours... It is the beginning! I can barely contain my excitement! What a great privilege it is to take command of our first comprehensive survey of life in this pond home of ours.

I must say the Cyclops is a most amazing ship – the perfect instrument for exploring the hidden worlds of the vast pond universe. It will take many months, and our voyage will undoubtedly hold many surprises – as well as perils. But the ship is tough and I am confident that the Cyclops and her crew can endure whatever adventures the pond inhabitants throw our way.

08:00 hours... With a cheerful ringing of the ship's bell we depart Duckweed Base and set a steady course for the open water. Our helmsman, Gyro, informs me that it will take several hours to reach our first survey site. Hopefully we are too small to be of any interest to the large vertebrates (fish and frogs) that inhabit the shallows near Duckweed Base.



MS Cyclops

Vehicle Dimensions

LENGTH	1 mm
BEAM	.65 mm

Vehicle Mission

Maximum speed	10 centimeters per minute
Maximum depth	2.5 meters
Mission duration	60 days

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- Captain
- Ship's Naturalist
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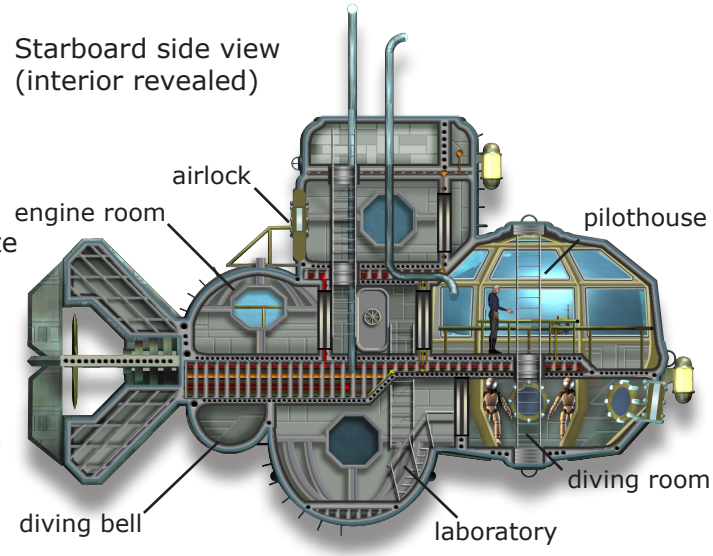
There are two onboard auxilary craft for specialized exploration: a *diving bell*, and a terrestrial *crawler/rover* (disassembled).

The glass enclosed pilothouse is a unique feature that allows for optimal observation of the surrounding aquatic environment.

Manipulator grabbers (claws) facilitate rapid making-fast and retrieving samples for study.

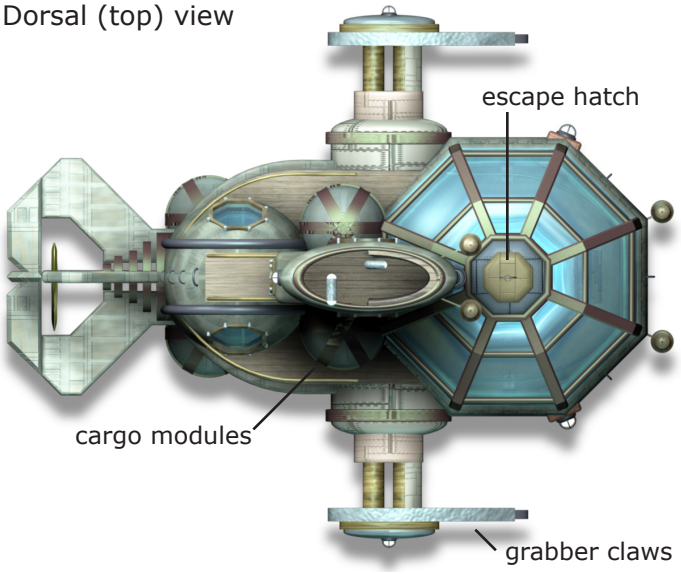
What if you were a scientist onboard the *Cyclops*? Imagine what the pond environment looks like to these micro sized explorers, only 50 microns (*µm)* tall. What unique problems might they encounter because of their size? How would they acquire repair materials, such as glass? Where would they find food, fuel, or oxygen?

Starboard side view
(interior revealed)



Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



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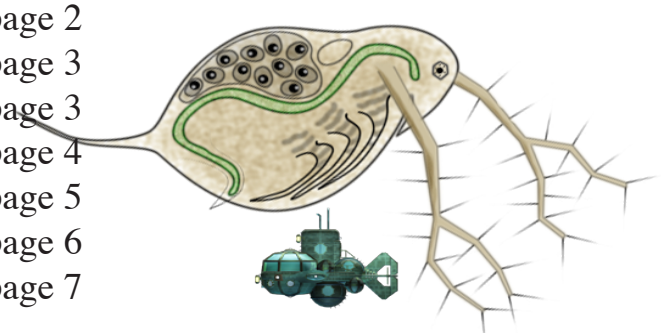


Daphnia, the water flea: 4-6 mm

About the Organisms

What is plankton?

Plankton is the name given to all of the freely drifting organisms found in the open water habitat of lakes, ponds, wetlands, and oceans.

Biologists often refer to planktonic animals as "zooplankton" and to plant-like organisms as "photoplankton."

Photoplankton is eaten by zooplankton, and zooplankton becomes food for small fish... and on up the food chain.

Copepods

Copepods are crustaceans, relatives of crabs and shrimp. They have a hard shell-like cover on their bodies and jointed appendages.

The largest copepods live in the ocean and are about 1 cm (centimeter) long. Most copepods in ponds are 4 mm (millimeters) long or less.

Copepods feed on tiny green cells (algae) that are also present in the pond (photoplankton).

Copepods that live in the open water hold their antennae out to slow their rate of sinking, holding them where they can find the most food.

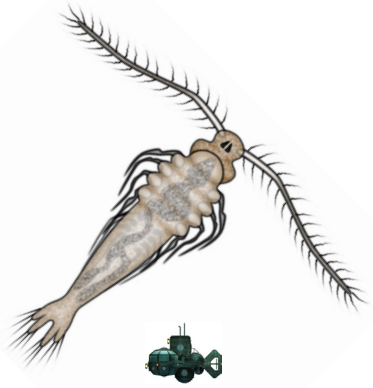
Their fan-like mouth parts create the currents that bring in food.

Copepods swim on their backs using five pairs of swimming legs.

The Log of Captain Jonathan Adler

Day 2: 07:30 hours... We have arrived at the region of the pond designated as the "open water." I have ordered the ship made ready for an exploratory dive to a depth of 150 centimeters.

17:55 hours... We are abruptly pulled off course by a sudden change in the water current. We soon see the source of the strange powerful current – it is the feeding vortex of a monstrous copepod!



Scale comparison to Cyclops

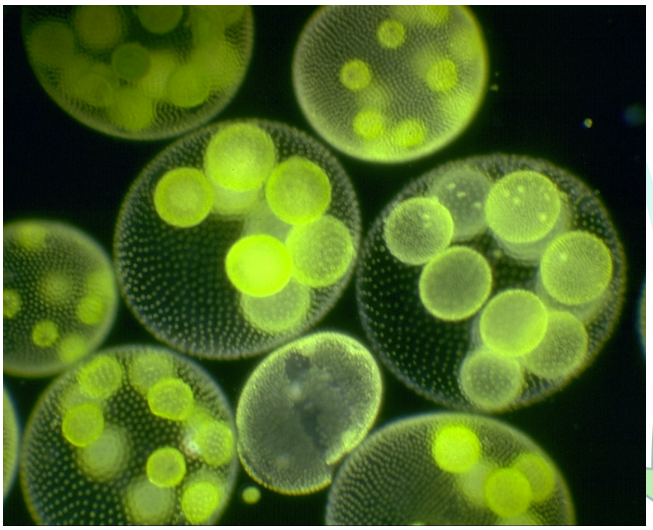
Trapped in the vortex we now have a terrifyingly close-up view of the copepod's fan-like mouth parts. These fans create a current in the surrounding water that draws in smaller organisms such as algae cells, and in this case the Cyclops!

We are now in danger of being crushed by the copepod's mouth. How will we escape this filter-feeding monster?

A thought: When an object too large to devour becomes trapped in the animal's feeding vortex, the beast must possess a simple way of rejecting it, like a reflex of some kind. That will be our only hope for escape.

Gyro, my crackerjack helmsman, suggests that perhaps a large air bubble would interrupt the copepod's feeding behavior for a moment... just long enough for us to make a quick getaway.

Volvox

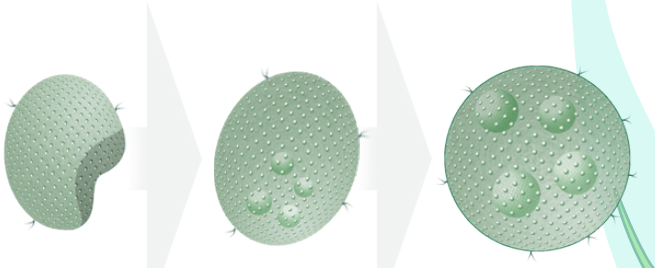


Great blooms of *Volvox* occur when nutrients wash into a pond during spring run-off.

The individual cells making up a *Volvox* colony carry out photosynthesis.

The spherical colonies measure about 500 micrometers in diameter – half a millimeter – and some *Volvox* get much larger, reaching 2 to 3 millimeters across.

Volvox reproduces asexually by producing daughter colonies.



The daughters begin as reproductive cells that divide to form a hollow ball of cells with a small pore on one side. Part way through development the daughter colony turns itself inside out through the pore.

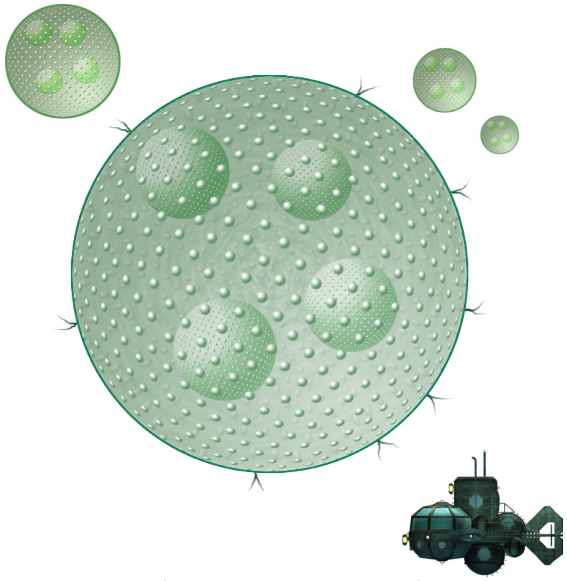
When daughters break out they leave their parent an empty hulk.

Before its pond dries or freezes, *Volvox* produces eggs and sperm.

The fertilized eggs (zygotes) develop a thick outer wall that protects the eggs from freezing and drying.

The Log of Captain Jonathan Adler

Day 3: 10:30 hours... Diving to a depth of 300cm we find ourselves drifting amongst a large population of beautiful green spheres. Each sphere contains a number of small spheres that appear identical to the parent.



Scale comparison to Cyclops

12:20 hours... After an exploratory dive, Lyra, our aquatic naturalist, has observed that the spheres are made up of smaller green cells, and that each of these has a pair of whipping flagella. We can deduce that this is how the large round colony spins and moves about. But how do the small single cells coordinate their efforts?

A closer look reveals that the cells are actually connected by lines! Perhaps these lines carry chemical signals between each cell in the colony that tell them how to direct their flailing flagella.

We observe these delightful orbs for some time. They are quite hypnotic to watch. A sudden surprise draws our attention! One of the large spheres splits open, and the smaller daughter colonies inside escape. This must be how **Volvox**, as this organism is called, gives birth to new colonies.

Daphnia

The Water Flea

Under a microscope *Daphnia's* clear body shows many features common to all advanced animals:

• an eye controlled by muscles with nerve connections to the animal's brain

• a heart that pushes clear circulatory fluid around the body

• special organs for oxygen uptake (pads on the rapidly moving swimming legs)

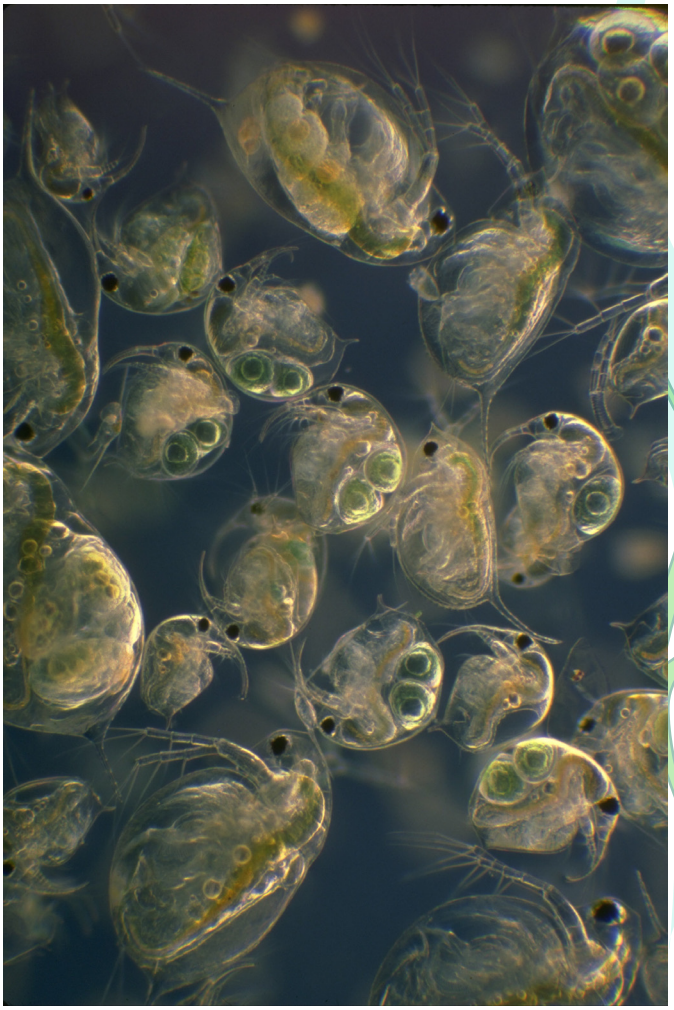
• jaws for grinding microorganisms captured on currents, produced by the swimming legs

• an intestine where the ground-up food particles are digested

• a protective outer shell

• a brood pouch for incubating young that hatch from large yolk-filled eggs

Like copepods, cladocerans become food for the larger predators of the pond.



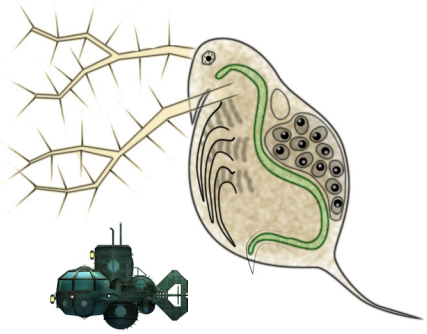
EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

Day 3: 14:30 hours... Collision! Emerging from the dark we strike a large object. The crash doors close automatically, so that we cannot see what hit us. Luckily, the ship suffers no serious damage

When the crash doors are unshuttered, we finally see the object that collided with Cyclops... it is a Daphnia, also known as the water flea.

Confident that the animal is stunned for a time, Lyra and I will leave the Cyclops in diving suits to get a closer look at the beast.



Scale comparison to Cyclops

The first impression is as if looking at a complex animal with the benefit of x-ray vision. We easily see through the Daphnia's clear shell, and can survey all of its internal organs.

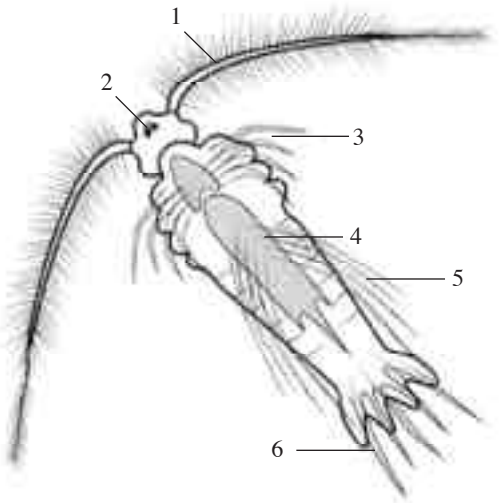
Its digestive system appears full of the single celled algae that make up its usual diet.

Its eye is a cluster of light receptors connected to it brain by nerves, and controlled by a network of muscles, very much like a human eye.

Its heart beats quickly, pumping a clear fluid through the animal's body, presumably delivering oxygen to muscles and organs.

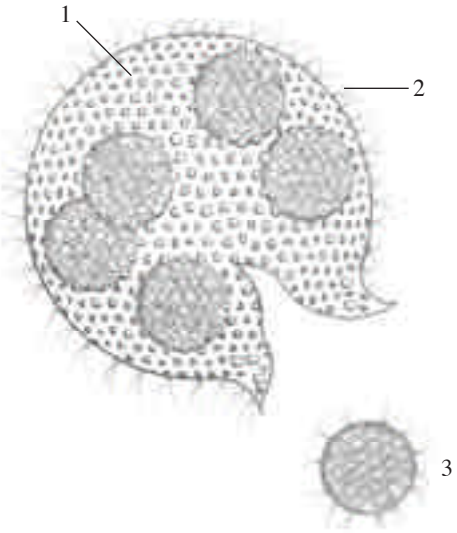
And in the back cavity, a cluster of developing eggs is plainly visible!

Key to Organisms



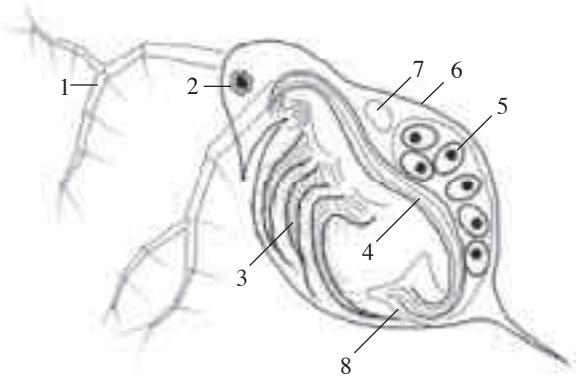
Copepod

1. antennae, for suspension
2. eyespot
3. feeding appendages
4. intestine
5. swimming legs
6. caudalsetae



Volvox

1. individual photosynthetic cells
2. flagella (two on each cell)
3. escaping daughter colony

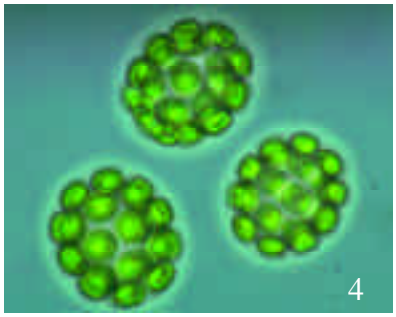


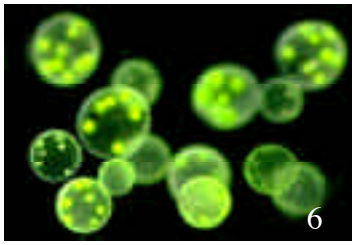
Daphnia

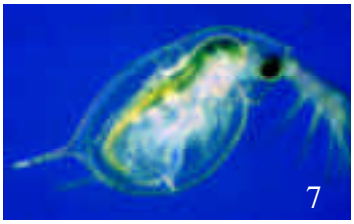
1. antennae, for suspension
2. compound eye
3. swimming feet
4. gut
5. summer eggs in brood chamber
6. carapace (shell)
7. heart
8. anus

Plankton Gallery

These organisms were collected from a small pond using a plankton net. As a biologist interested in classification, organize this set of organisms into what you would consider to be groups of relatives.







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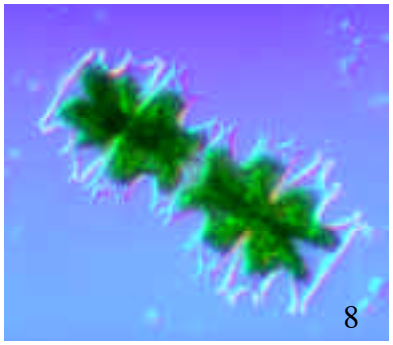

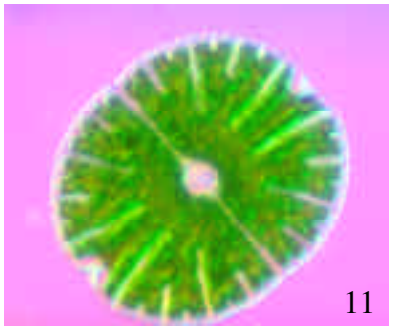

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A Monster in the Shallows
The Bacterium that Came to Dinner
Voyage to the Bottom of the Food Chain
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Forest Floor Explore
The Great Termite Kingdom
Province of Plant Prospectors
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Accompanies Episode 2 of the 13-part video series

Photosynthetic Fauna

Written by Eric R Russell & Bruce J Russell

In this episode...

The *Cyclops* crew observes a kind of *Paramecium* that hosts green algae cells within its body. They wonder how this relationship helps each organism. Later, a single algae cell is rescued and its green secrets revealed through experiments. The ship's naturalist discovers that in the presence of light, the green cell generates oxygen, along with several kinds of food molecules. This process is called **photosynthesis**.

Pond Ecology: Open Water & Weedy Shallows

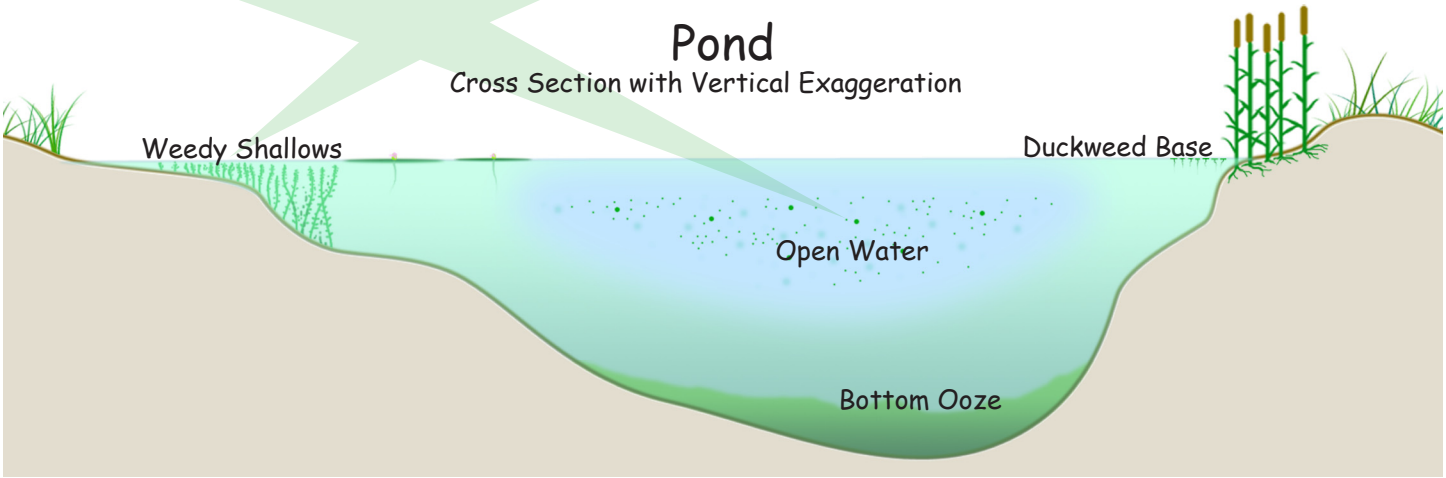
The Log of Captain Jonathan Adler

Day 3: 08:40 hours... Cruising at slow speed near the surface, the Cyclops encounters a large single-celled organism common throughout the pond – a paramecium.

This particular species of paramecium is different than the others we have seen – it is green! A closer inspection reveals that the green coloring comes from smaller green bodies inside. And these smaller green bodies are organisms themselves – algae cells!

The green cells inside do not appear to be the paramecium's lunch. We wonder what function they serve, or if their home inside the paramecium is simply a safe place to live, out of harm's way.

We have seen similar small green cells living independently throughout the sunny regions of the open water, thriving wherever sunlight is constant.



MS Cyclops

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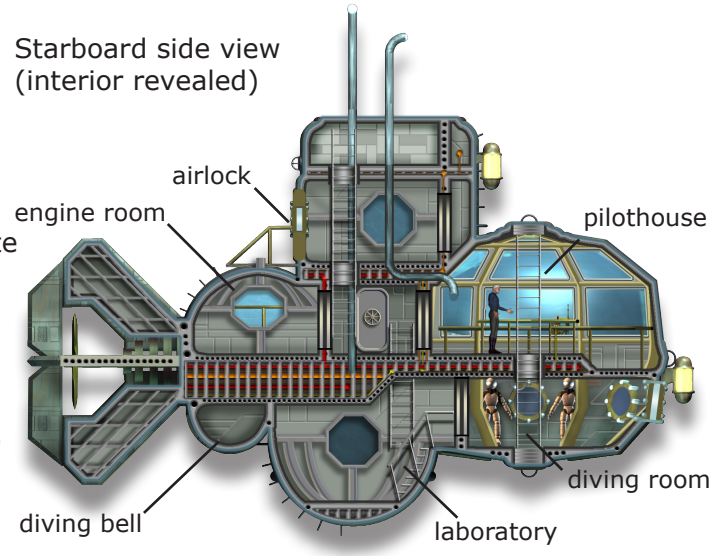
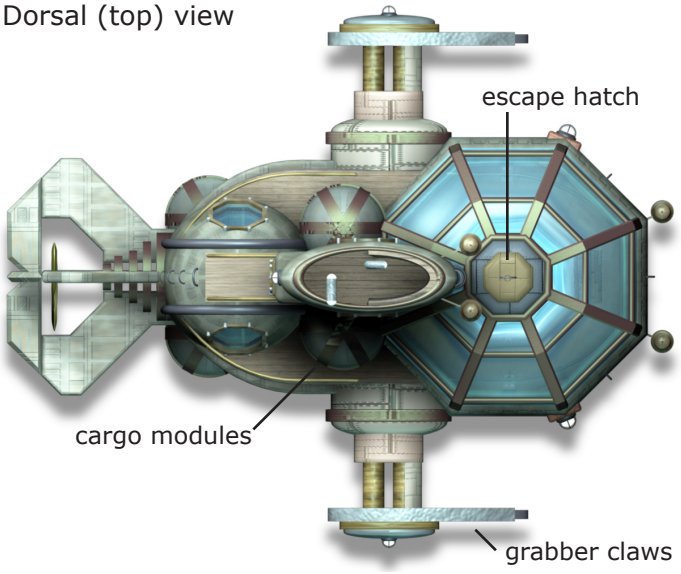
What if you were a scientist onboard the *Cyclops*? Imagine what the pond environment looks like to these micro sized explorers, only 50 microns (*µm)* tall. What unique problems might they encounter because of their size? How would they acquire repair materials, such as glass? Where would they find food, fuel, or oxygen?

Starboard side view
(interior revealed)



Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



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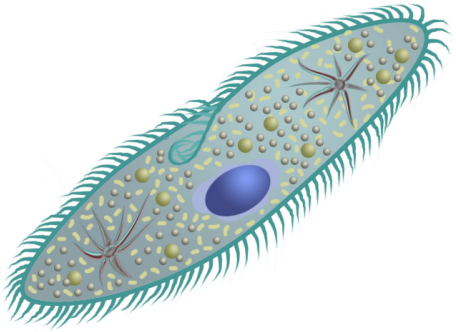
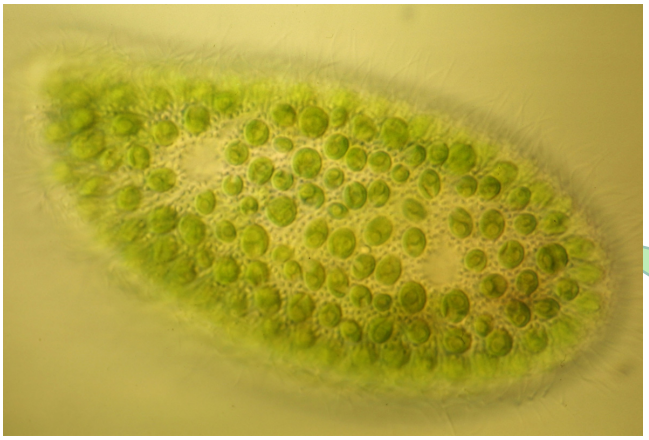


Paramecium caudatum: 750 *µm*

About the Organisms

Paramecium bursaria

Paramecium bursaria, the green paramecium, is filled with symbiotic algae cells.



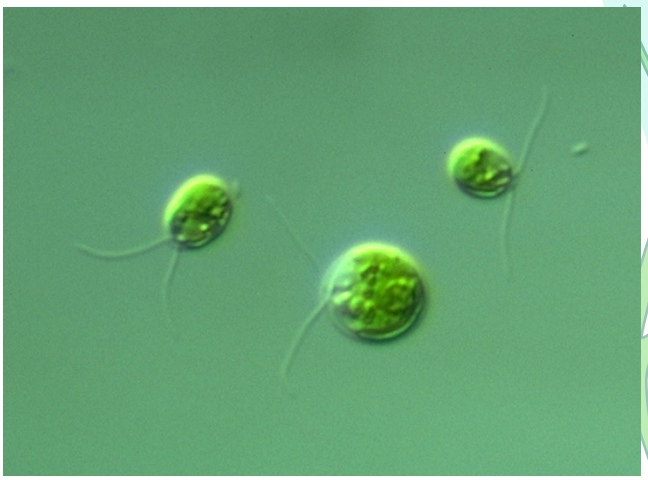
The algae make food molecules by photosynthesis and share some of these food products with their large host.

The paramecium provides its small green guests with the raw materials needed for photosynthesis, and a relatively safe environment in which to live.

The relationship between the green algae cells and the paramecium is called a symbiotic relationship.

Chlamydomonas

Chlamydomonas is a small single-celled algae.



Like many algal protists *Chlamydomonas* is a flagellate, using its pair of whip-like strands to propel itself through the water.

It travels to levels in the pond where sunlight is strong enough for photosynthesis, but not so strong that it cooks the cell.

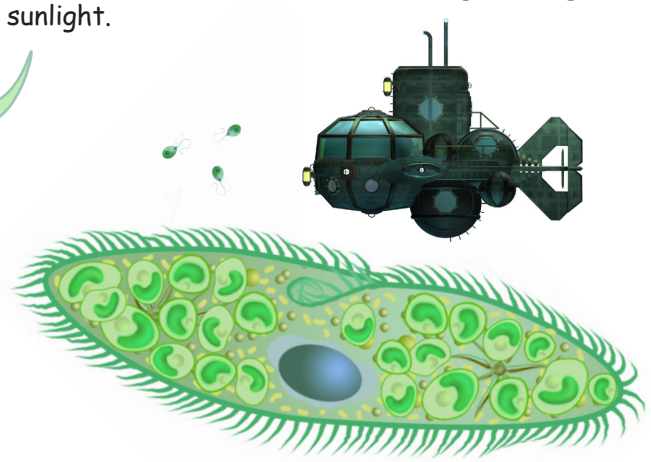
EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

Day 3: 10:30 hours... A surprise! When we pass over the green paramecium, the Cyclops blocks the light from hitting it – and to our astonishment, the organism immediately moves back into the sunlight!

Could the paramecium be moving back into the light for the benefit of its little green guests?

We have observed that green microorganisms gather in sunny patches of the pond. Further observation is needed to learn the connection between green organisms and sunlight.



Scale comparison to Cyclops

12:15 hours... Gyro sounds the bubbles above" alert.

Air bubbles are a particular nuisance to the Cyclops. The reason is we could easily become trapped by surface tension between air and water, and be unable to escape. We must avoid these algae-generated oxygen bubble rafts at all costs.

To avoid rising into the bubble raft we must add weight to the ship. As time runs out I order the oxygen tanks flooded with water – and thankfully the Cyclops stops rising. However, now our oxygen supply is dangerously low. To make matters worse, Gyro reports something is impairing the ship's steering system. What now?

Lyra puts on her diving suit and leaves the ship to see if she can discover the problem with the rudder, and is surprised by what she finds!

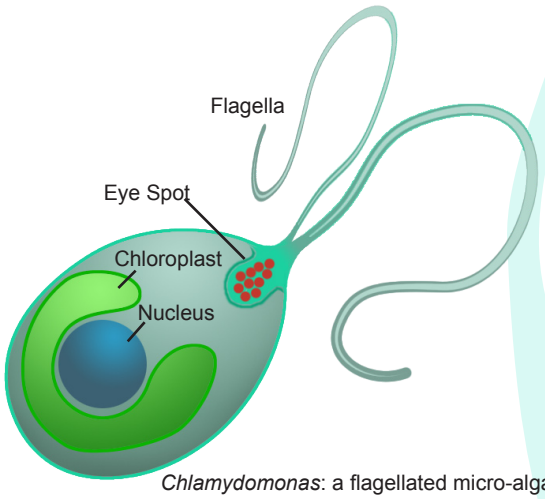
Where Energy Comes From

Life takes energy. In the world of humans, we get energy from the food we eat. If we eat a bowl of rice, the rice came from rice plants that grew in a field with sunlight, water, and nutrients from the soil. If we eat a piece of fish, that fish ate smaller fish, which ate tiny aquatic insects, which ate microscopic algae such as *Chlamydomonas*.

Plant cells and algae cells have one thing in common: they are green. The green coloring comes from small bodies inside the cells called **chloroplasts**. *Chlamydomonas* has a single chloroplast shaped like a horseshoe.

When sunlight hits a chloroplast in a plant or in an organism like *Chlamydomonas*, energy from the light causes a **chemical reaction** that makes high-energy **food molecules**... and produces **oxygen** as a waste product. This chemical process uses **photons** of sunlight to **synthesize** food energy molecules.

We call the process **photosynthesis**.



Chlamydomonas: a flagellated micro-alga

Photosynthesis

- a function of plant and algae cells
- occurs in the chloroplast of the cell
- requires sunlight, water, carbon dioxide
- converts light energy, water, and carbon dioxide into simple starch (basic food molecules)
- produces oxygen as a waste product

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

14:30 hours... To our delight, Lyra discovers a single greenish cell caught in the ship's rudder assembly. When she attempts to free the organism it takes her on a merry jaunt as she grasps the tether with all her strength.

Not wanting to lose my prize naturalist, I set about a quick plan to lure the green cell close enough for capture. I suddenly remember our recent encounter with the large green paramecium, and how it would move out of our shadow to bask in the sunlight. Perhaps this energetic green organism has a similar habit.

I turn to the ship's controls and power up the external lamps. Sure enough, as I had hoped, the organism changes its mad course and heads toward the light.

15:15 hours... Lyra is now safely aboard the Cyclops again and our new mascot – the green algae cell – is being observed in a glass enclosure.

It has the usual characteristics of a single cell: a roundish clear body filled with cytoplasm. This one has two flagella, which it uses like propellers for moving about. Each flagellum joins the body where we observe a cluster of red granules. We suspect this red "eye spot" is sensitive to the presence of light, and steers the cell by sending chemical signals to the flagella.

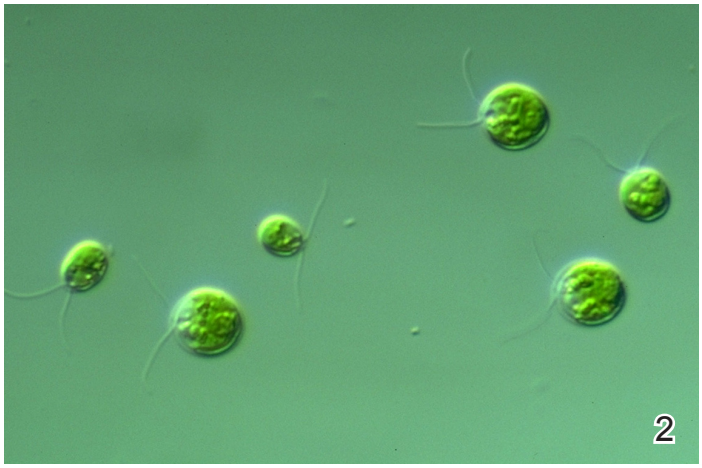
Also inside the cell is a nucleus, a number of whitish starch bodies, and a curved green structure. This is the organism's chloroplast. When light is shined upon it, the oxygen levels in the tank begin to rise and more starch bodies are produced. We believe we are watching the process of photosynthesis as it occurs.

Lyra suggests that a small zoo of these organisms might serve us by producing all the oxygen we could ever need! It appears that a happy accident has provided us with a solution to our oxygen problem.

As we continue our mission I am in awe. We have observed that every green cell in this life-rich world is a living factory, producing oxygen and the molecules for life. It is here in the micro world, I humbly realize, that the foundations of the living world begin!

Gallery of Organisms in this Adventure

The crew of the Cyclops encountered two photosynthetic organisms in this adventure. A freshwater pond, wetland, or lake contain many different species of single-celled producers – the word we use for organisms that make their own food from photosynthesis. Here are a few.



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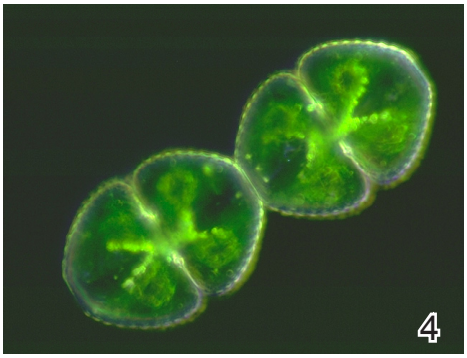

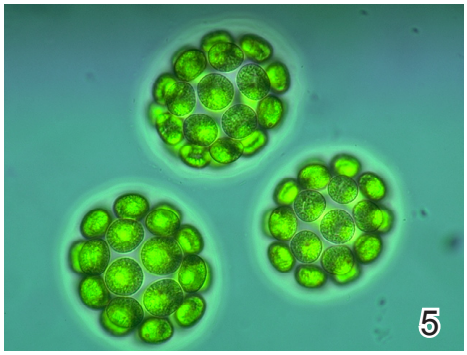

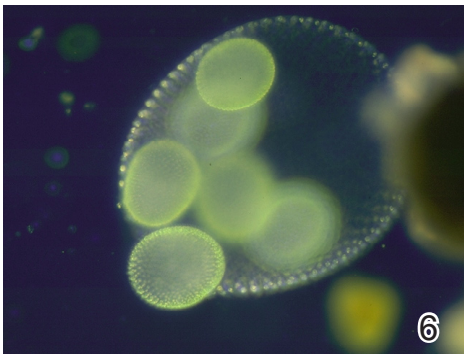

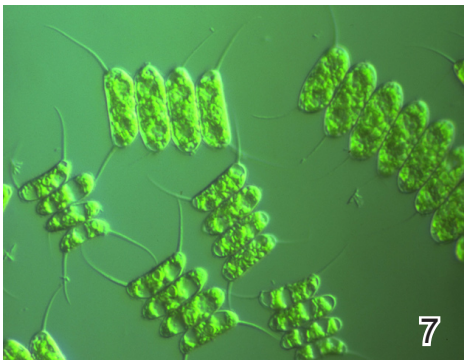

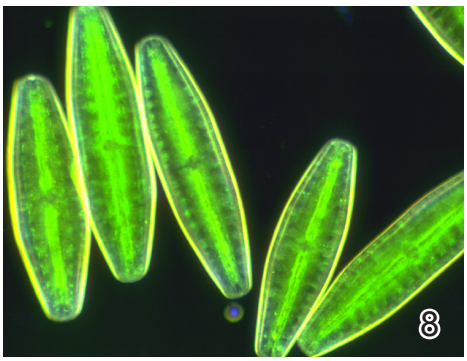

The Freshwater Adventures Volume, 13 Episodes

Perilous Plankton
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A Monster in the Shallows
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Accompanies Episode 3 of the 13-part video series

Plagued by a Predator

Written by Eric R Russell & Bruce J Russell

In this episode...

The *Cyclops* crew is making a documentary film of their discoveries throughout the pond. In the life-rich weedy shallows they encounter many single celled (**protists**) and multi-celled (**animals**) organisms. A story of **ecology** unfolds and gives them a greater understanding of the **diversity** of the life in the micro world – an **ecosystem** as rich with predators and prey as the African savanna. As they complete their filming expedition, they become potential prey to a predator of the weedy shallows – a **Planarian**, or flatworm. Quick thinking allows them to escape, and they get to watch how the Planarian hunts and feeds in the process.

EXPLORATION GUIDE & JOURNAL

Pond Ecology: Weedy Shallows

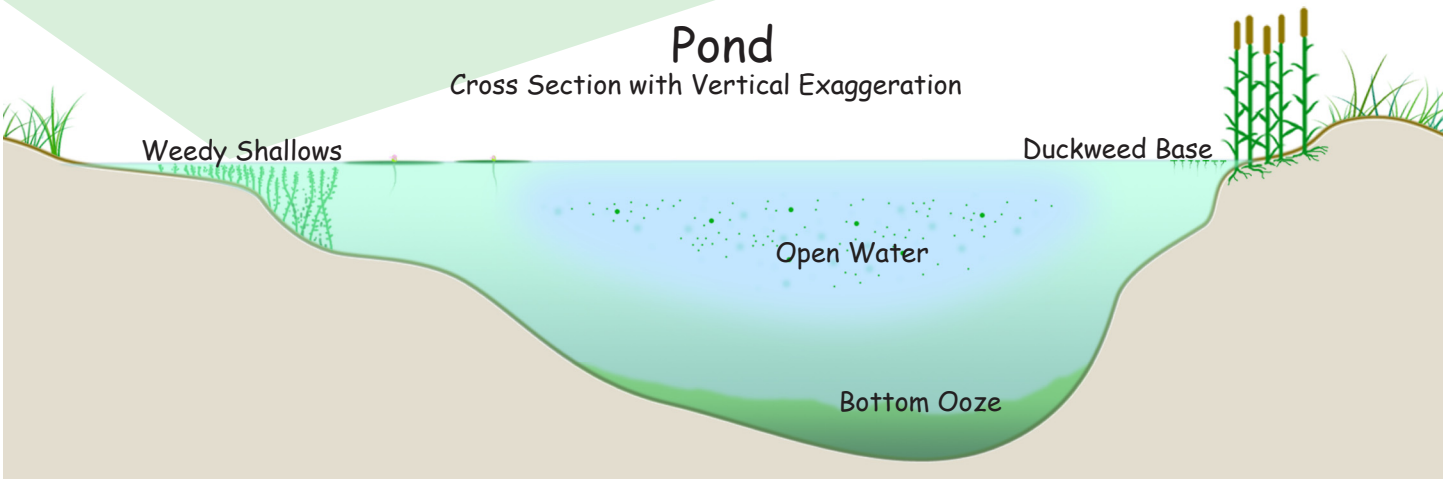
The Log of Captain Jonathan Adler

Day 9: 10:15 hours... Lights, camera, action! The film is rolling! We are now several days into the production of a documentary motion picture. When finished, our film will feature the numerous kinds of microscopic organisms found throughout the pond.

We are currently navigating our way through the dense and treacherous weedy shallows. Because of the aquatic plant life and plentiful sunlight, this region offers safe haven for an abundance of microorganisms.

Again and again we see (and film) the relationship between organisms that hunt – and organisms that graze. The hunters, or predators, capture and devour the others. The lion feeds on the zebra.

The grazers, or prey, do not hunt. Some are green and use photosynthesis to harvest energy from sunlight. Others suck up decomposer bacteria from rotting leaves and decaying micro animals. The zebra eats the grass.



MS Cyclops

Vehicle Dimensions

LENGTH	1 mm
BEAM	.65 mm

Vehicle Mission

Maximum speed	10 centimeters per minute
Maximum depth	2.5 meters
Mission duration	60 days

The microsubmersible *Cyclops* is designed for extended exploration of freshwater ponds, streams, and wetlands. The vehicle carries a standard crew of four.

- Captain
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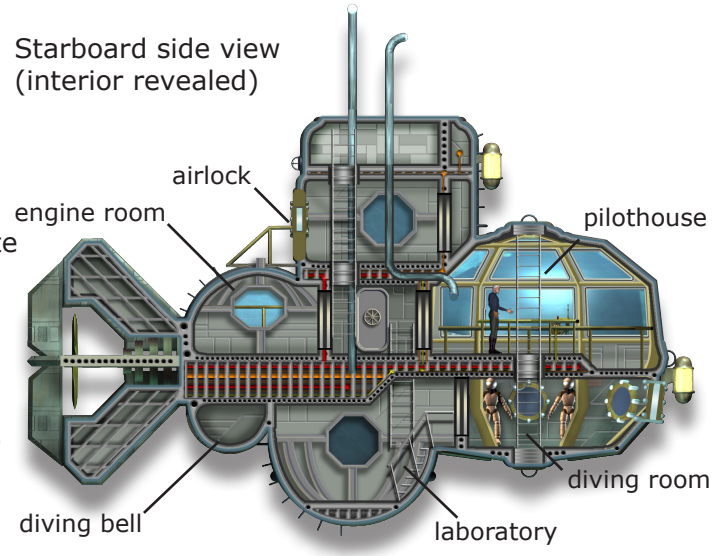
There are two onboard auxilary craft for specialized exploration: a *diving bell*, and a terrestrial *crawler/rover* (disassembled).

The glass enclosed pilothouse is a unique feature that allows for optimal observation of the surrounding aquatic environment.

Manipulator grabbers (claws) facilitate rapid making-fast and retrieving samples for study.

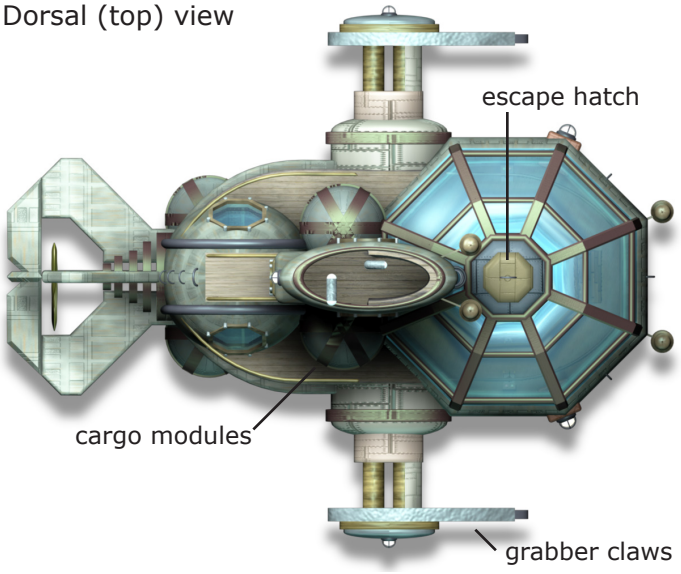
What if you were a scientist onboard the *Cyclops*? Imagine what the pond environment looks like to these micro sized explorers, only 50 microns (*µm)* tall. What unique problems might they encounter because of their size? How would they acquire repair materials, such as glass? Where would they find food, fuel, or oxygen?

Starboard side view
(interior revealed)



Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



Contents of this guide...

Euglena: 50 *µm*

About the Organisms

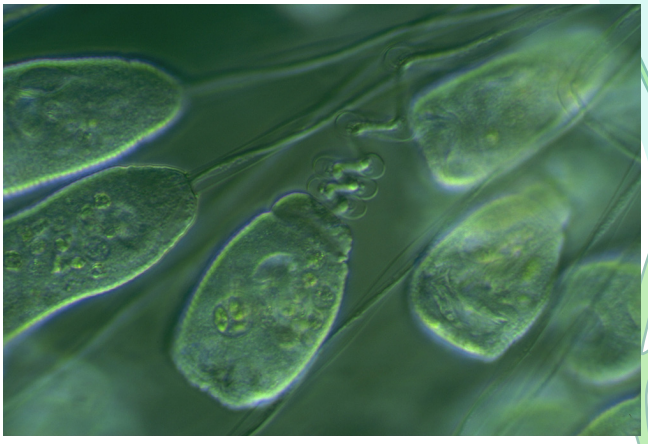
What are protozoans? What is algae?

Three varieties of free-living single-cells populate the freshwater micro world of ponds, streams, lakes, and wetlands.

- **Bacteria**
- **Protozoans**
- **Algae**

Bacteria are simple single cells. They can be long strands, short rods, or strings of cells. A bacterium has no nucleus. Bacteria are one of the simplest forms of life on earth. They decompose dead planets, animals, and other single-celled organisms.

Protozoans and **algae** are also single celled organisms, but they are far more complex than bacteria. These cells have a nucleus, just like the cells in multi-cellular organisms (plants and animals). Protozoans are classified by how they move: ciliates, flagellates, and amoebas. Algae contain green chloroplasts and acquire energy through photosynthesis.



Vorticella

Vorticella is a ciliated protozoan that attaches to objects in the water by a **contractile stalk**. Vorticellids are found in clusters often large enough to be seen with the naked eye.

Vorticella uses a ring of rapidly beating **cilia** to create a feeding vortex, a whirlpool that pulls bacteria and small algae cells into its mouth.

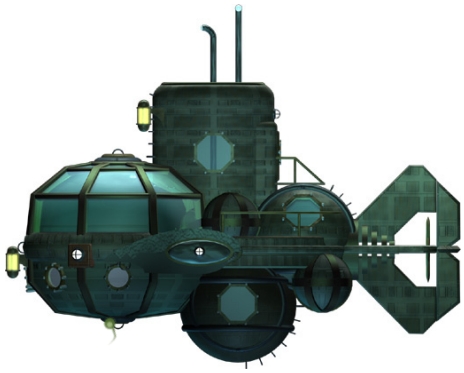
EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

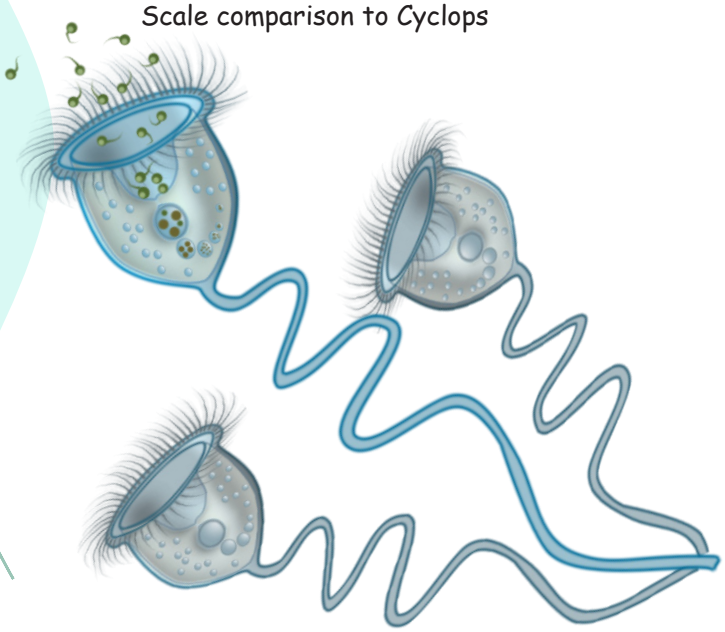
Day 9: 7:30 hours... Deeper into the weedy shallows now.

When complete, our documentary will reveal that the micro world is a living dance of predators and prey, of survival at all costs. Let us hope that we finish it before becoming prey ourselves!

17:30 hours... **SPROING!** We've just observed a most amazing microorganism that tethers itself on a spring-loaded stalk. When danger approaches the cell instantly retracts the stalk, jerking itself quite suddenly out of harm's way. After a time the stalk relaxes and the cell resumes feeding – a process of drawing in small algae and bacteria that become caught in its whirlpool-like feeding vortex.

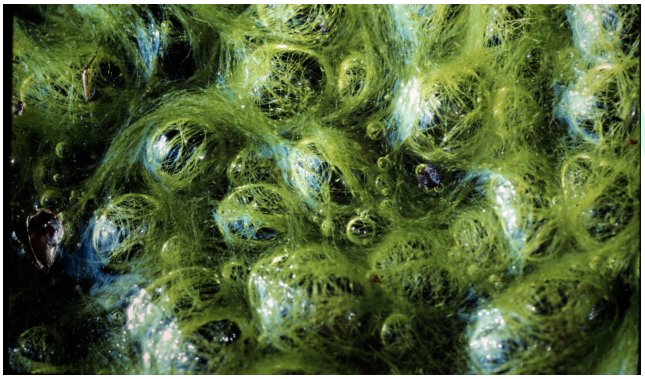


Scale comparison to Cyclops



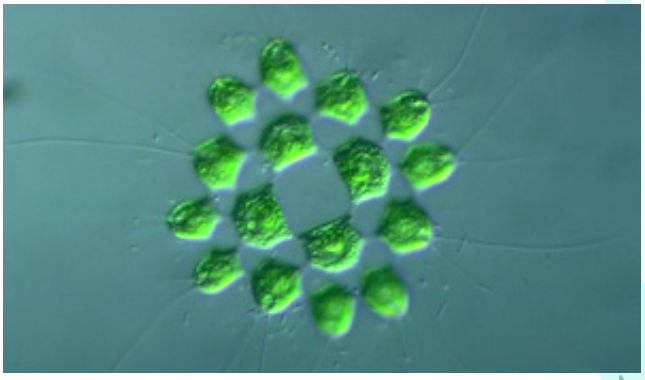
Spirogyra

Spirogyra is a common thread alga made up chains of cells, each with a spiraling chloroplast and clearly visible nucleus.



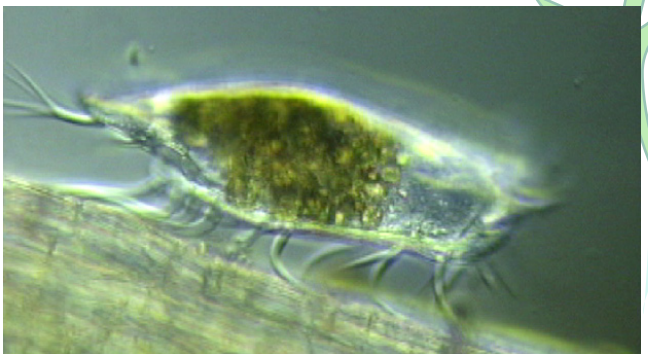
Gonium

Gonium is a simple algae colony made up identical cells. Each *Gonium* cell is **photosynthetic**, obtaining energy from sunlight and giving off oxygen as a waste product. *Gonium* has a single **flagella** – a whip-like strand for moving through the water. This is how the colony orients itself into the best position for collecting sunlight.



Euplotes

Euplotes is a ciliate whose **cilia** are fused into appendage-like structures called **cirri**. The cirri allow *Euplotes* to walk over surfaces, hunting for small green algae cells. It's favorite food is *Chlamydomonas*. *Euplotes* holds its food in a food trap before engulfing and digesting it.



EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

8:15 hours... We are encountering so many new organisms that our camera is rolling constantly!

We spy a type of algae made up of cells that connect to each other end-to-end, creating extremely long strands, like hair. The green chloroplast in these cells is spiral shaped, which likely allows it to receive sunlight for photosynthesis no matter where the strand is drifting in relation to the sun.

Nearby we film a busy cluster of green colonies. The individual green cells have two flagella each, and are able to keep their small colony of sixteen cells facing the sun for efficient photosynthesis.

And then a big surprise – a ciliated microorganism that walks! This beasty patrols stems and branches of pond plants, hunting algae. Its legs appear to be specialized cilia that are fused into limbs.

Scale comparison to Cyclops

Amoeba

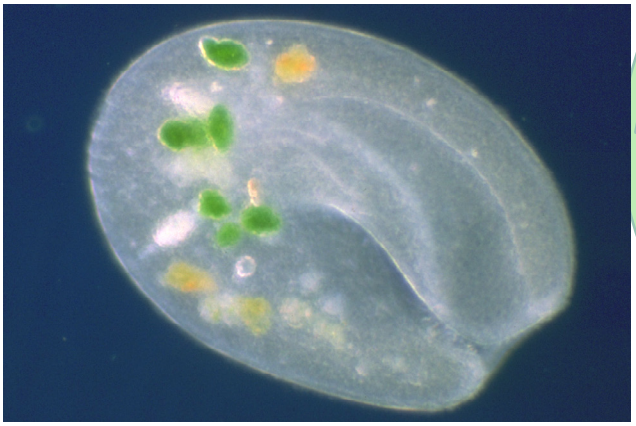
Amoeba moves and engulfs food by cell extensions called pseudopods. There are many different kinds of **amoebas**, some very tiny, others large enough to see with the naked eye.

Euglena

Euglena is a photosynthetic **flagellate**. There are many kinds (species) of euglinids found in virtually all freshwater environments.

Bursaria

Bursaria is a giant **ciliate** easily visible to the naked eye. Bursaria travels mouth first, engulfing smaller cells in its path.



EXPLORATION GUIDE & JOURNAL

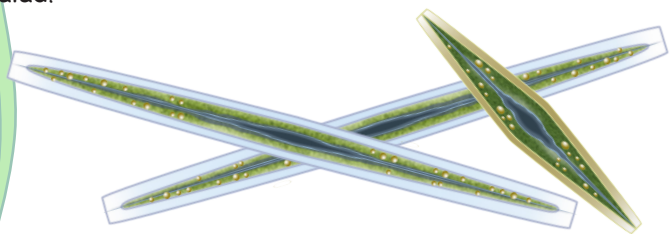
The Log of Captain Jonathan Adler

10:35 hours... Diatoms surround us! Every cell of this single-celled algae encases itself within a house of glass. Equally as fascinating is how it buoys itself to hold position at the best depth for photosynthesis; it uses lighter-than-water oil droplets! Ingenious!

Glass, as we know, is made of silica. Where might the diatoms extract silica for making their glass houses? And that oil – we know is very high in carbon; from where, we wonder, do they get it – or how might they synthesize it?

Some time back we discovered many uses for these interesting cells. All of the windows and portholes aboard the Cyclops are made from glass harvested from diatoms. We use the oil droplets for fuel and machinery.

Some are green, and some yellow – but I must tell you that the chloroplasts of all varieties make a delicious salad!



12:00 hours... We are filming so many different species of single-celled organisms! How do these free-living protozoa move about? Our film has revealed that all independently living cells fall into one of three groups.

The Amoeboids: Amoebas and their relatives move by extending blob-like appendages that flow like living putty.

The Flagellates: A long whip-like strand, or bundle of strands, wave rapidly, pulling the cell through the water like a propeller.

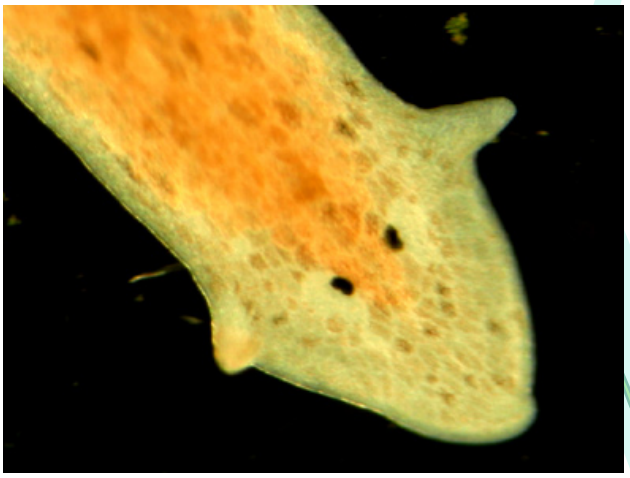
The Ciliates: These cells are usually covered in a coat of small hairs that move wave-like, in any direction, to move the cell. This is the most diverse family of single cells. Some have cilia adapted for walking, others for feeding. Ciliates are the speedsters of the microscopic world, and most are much faster than the Cyclops at full-steam!

Planaria

Planaria is a voracious predator of the pond's weedy shallows. This habitat provides hiding places for this flatworm, a versatile feeder able to seek out and scavenge dead organisms, as well as hunt live prey.

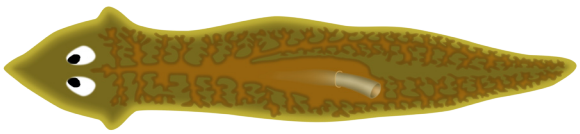
You will never forget Planaria once you have looked into its crossed "eyes." Planarians belong to a group of invertebrate animals that also includes flukes and tapeworms.

Planaria's "eyes" are light sensitive pots that allow planarians to avoid direct sunlight, thus they spend most of their time on the underside of rocks and leaves.



The ear-like projects are loaded with chemical receptors. Moving its head from side to side allows a planarian to sense the gradient of chemical signals diffusing out from a food source, allowing it to home in on food.

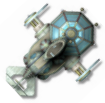
Planarians and their relatives have mouths located in the center of the bellies. A feeding tube extends through the mouth opening and sucks in the food, which is distributed through the worm's three-branched intestine.



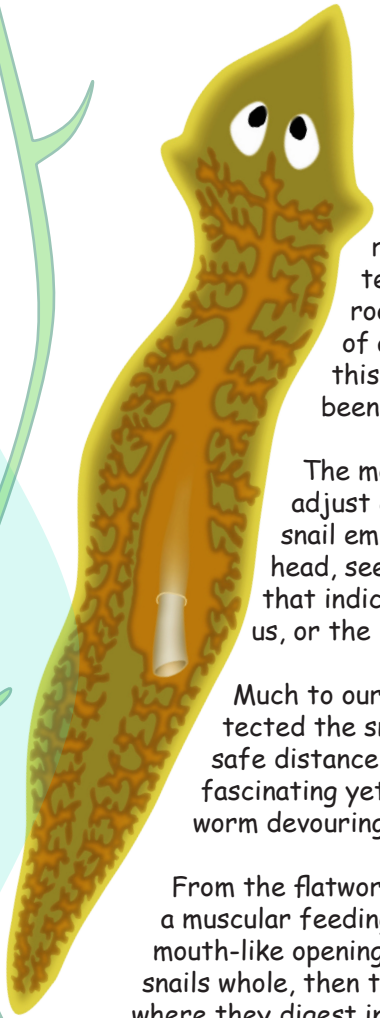
EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

15:15 hours... Our demise may be at hand! A predatory flatworm has caught our scent, probably sensing the excess carbon dioxide from our air filtration system. We are trying to evade the beast, but to no avail. We can neither outrun it, nor out-maneuver it in the aquatic weed forest. At every turn the worm sways its enormous head from side to side, using its ear-like chemical detectors to track our every move. I fear that unless we find a way to distract the monster, and soon, we shall become this flatworm's afternoon snack!



I am moments from making a fateful decision – the command to abandon ship. Perhaps if the predator captures the Cyclops, we can escape in diving suits. Just then Barron, my sturdy engine master, calls out from the engine room! He has sighted a clutch of aquatic snail eggs! Could this be the distraction we've been hoping for?

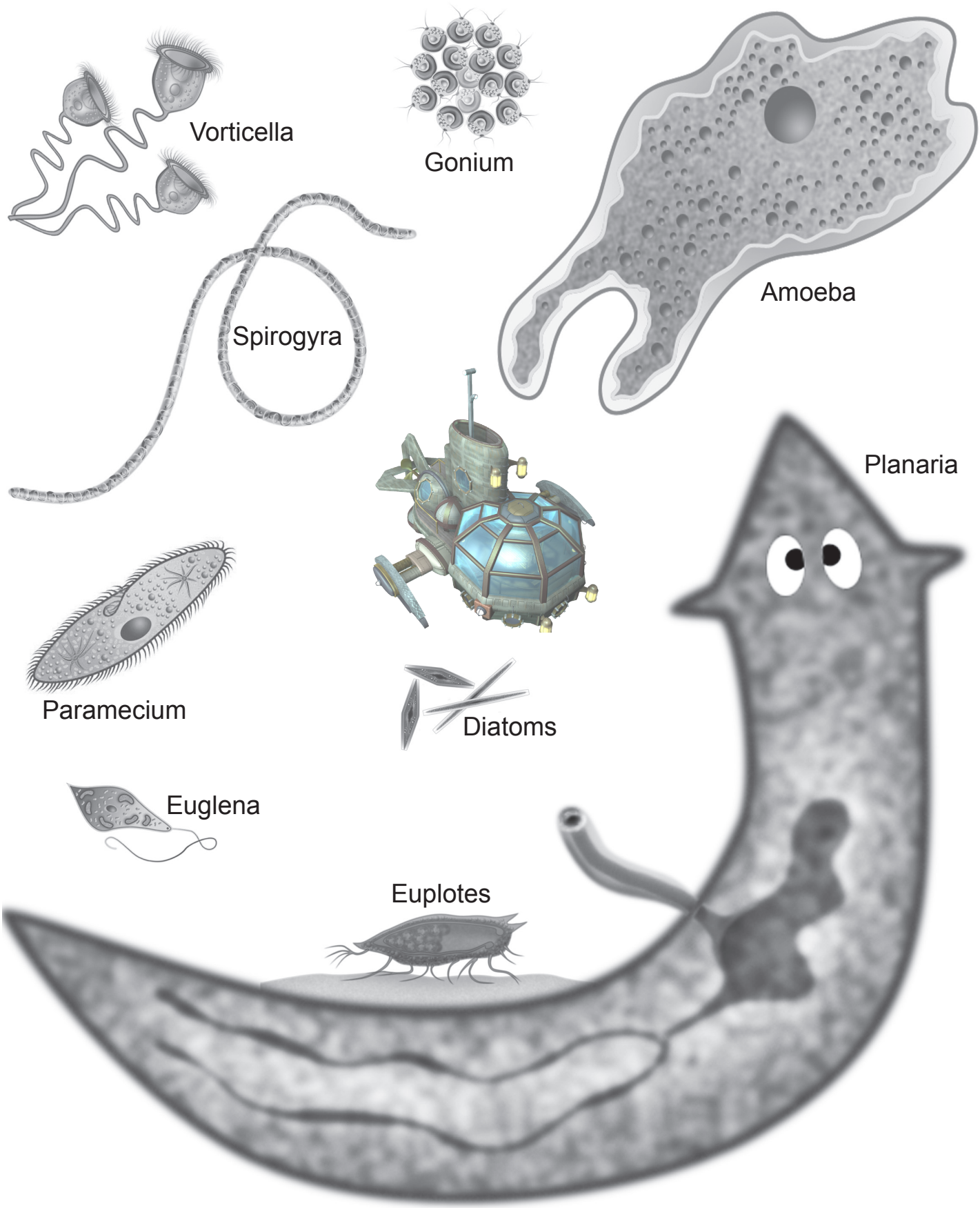


The monster is nearly upon us! We adjust course and steer toward the snail embryos. The worm wags its head, seeking the strongest signal that indicates an easy meal. Will it be us, or the baby snails?

Much to our relief, the worm has detected the snail eggs. We withdraw to a safe distance from where we observe the fascinating yet gruesome process of the worm devouring the baby snails.

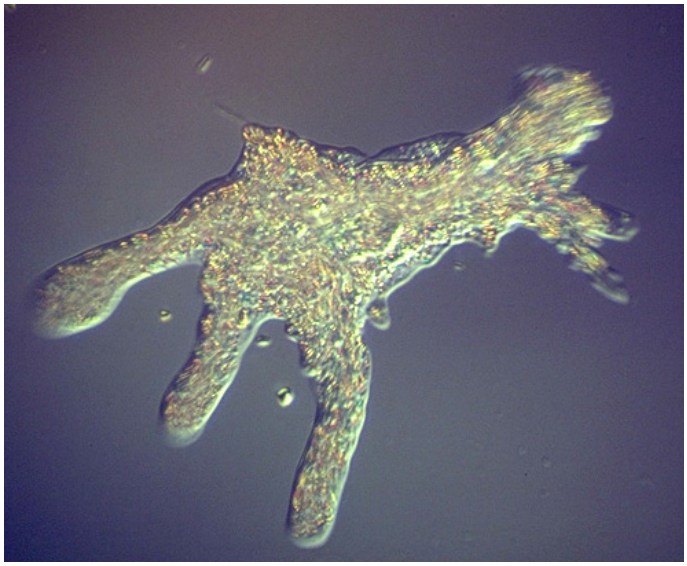
From the flatworm's underside emerges a muscular feeding tube. The tube has a mouth-like opening that swallows the baby snails whole, then takes them into its body where they digest in its 3-branched intestine.

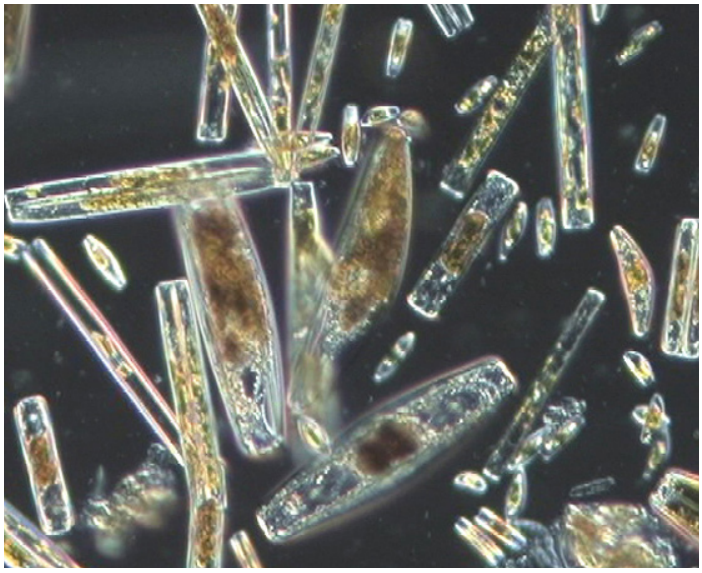
Key to Organisms



Gallery of Organisms in this Adventure

The crew of the Cyclops encountered many single celled organisms, and one giant predator animal in this adventure. They learned that organisms in the micro world move about by different methods. The method they use for moving may help them find food, or escape from predators.





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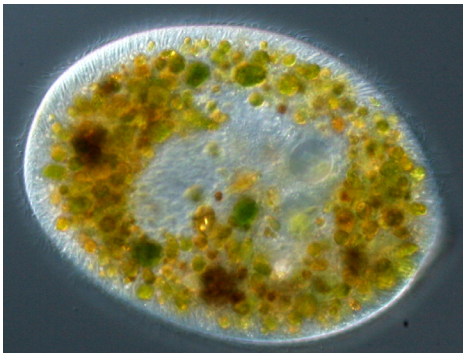

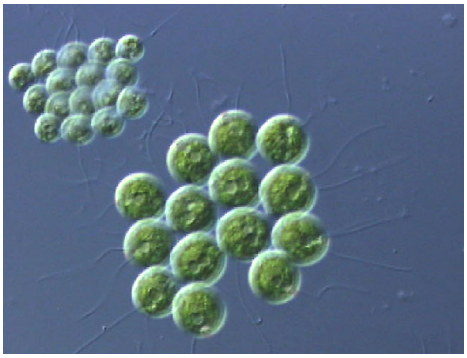

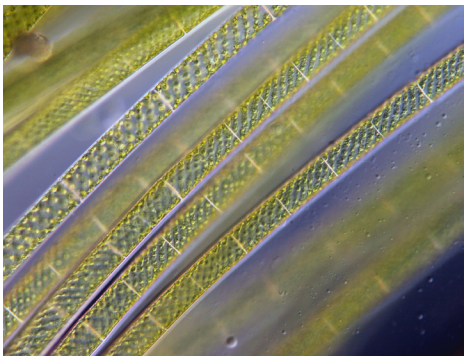

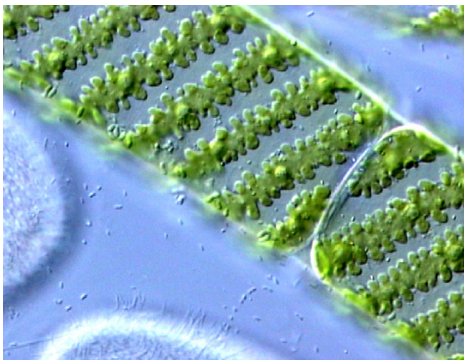

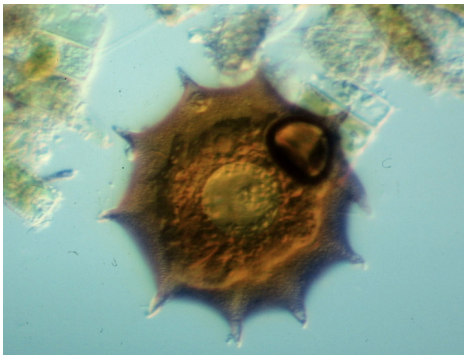

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MICROSCOPIC MONSTERS

Accompanies Episode 4 of the 13-part video series

A Monster in the Shallows

Written by Eric R Russell & Bruce J Russell

In this episode...

While navigating the dense aquatic weed forest of the pond shallows, the *Cyclops* is pulled off course by a tentacled animal called *Hydra*. With quick action by the crew they barely escape. They begin observation of *Hydra*, how it reproduces, and how the predator feeds and digests captured prey. The ship's naturalist volunteers to take the diving bell on a mission inside the hydra's gut to observe digestion from inside the animal's stomach.

EXPLORATION GUIDE & JOURNAL

Pond Ecology: Weedy Shallows

The Log of Captain Jonathan Adler

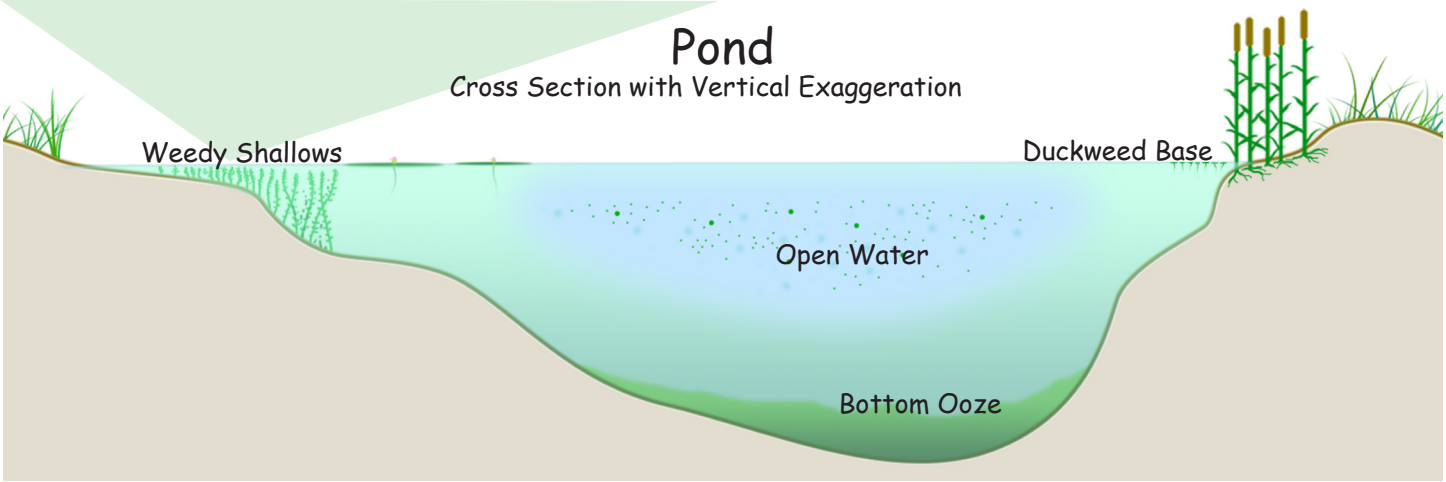
Day 10: 09:00 hours... Trying to make our way clear of the dense weedy shallows the ship is suddenly grabbed by a tentacled monster and held tight in its arms. Even under full power we are unable to escape!

A glance outside reveals that we are being drawn toward the creature's mouth. It obviously intends to swallow the Cyclops whole!

As we stare helplessly down the gullet of the monster, Lyra suggests a plan that might force the animal to release the Cyclops: electrifying the outer hull. Engine master Barron connects the ship's batteries to the hull plating and throws the switch.

With the crackle of electricity and the smell of ozone the ship lurches free. The monster releases the Cyclops. We steam away to safety and watch the beast from a safe distance.

In her biological research key, Lyra discovers that this animal is called Hydra, named after the many-headed serpent of ancient Greek mythology.



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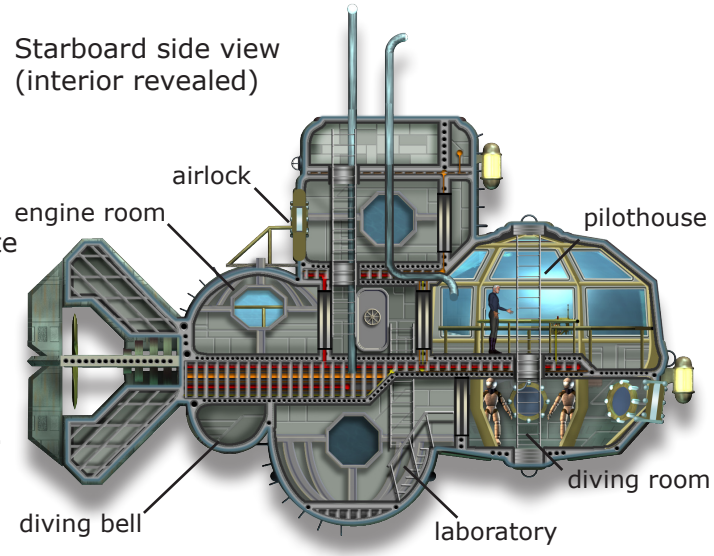
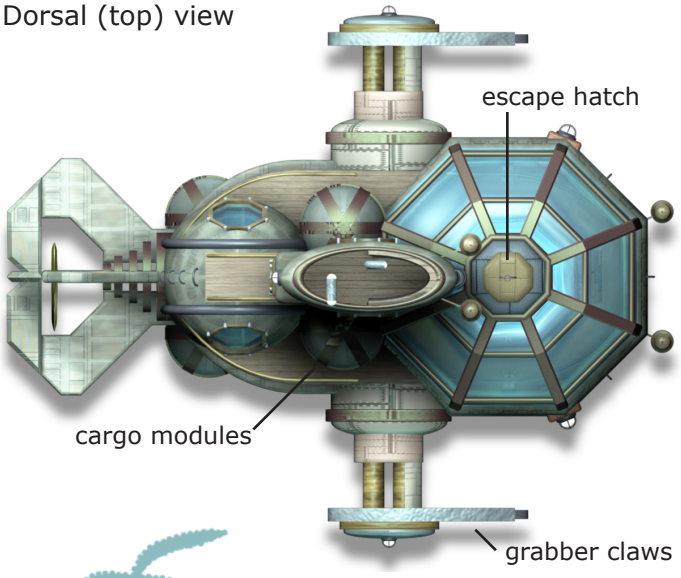
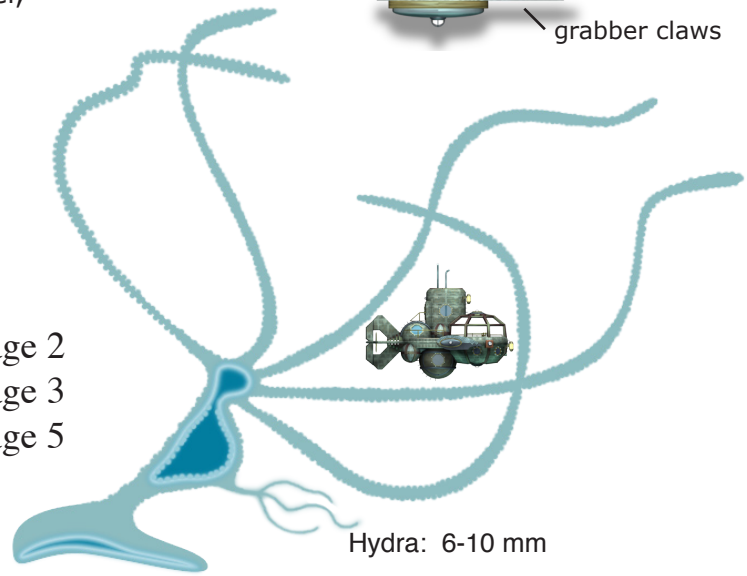


Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view





Hydra: 6-10 mm

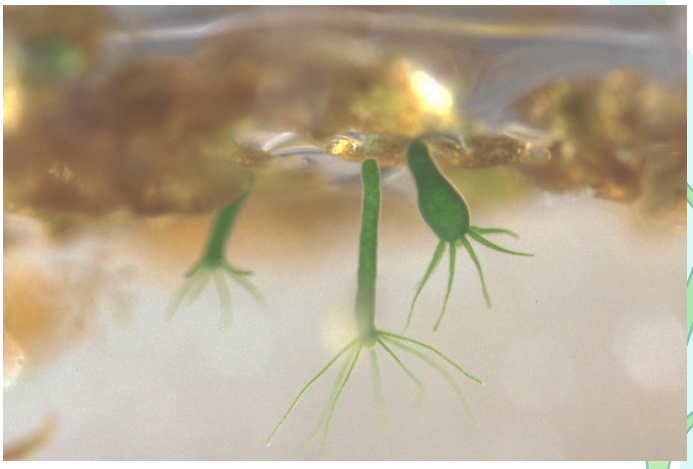
Contents of this guide...

About the Organism

Hydra
A Monster of the Microcosm

Hydra is a predator of weedy shallows. Because they live attached to plants and other underwater surfaces, hydras are easy to collect and study with a hand lens or microscope.

Green hydras show up best against white, light colored ones against dark backgrounds. If duckweed is present (tiny, bright green floating leaves with rootlets hanging below), check the hanging rootlets — a favorite attachment site for Hydra.



When examining try different lighting methods to see Hydra's anatomy.

- Do any have **buds**? What are they?
- Have any of your hydras eaten recently?
- Can you see the little bumps on the tentacles where stinging cells are housed?
- Do any hydras protozoans running about on their bodies and tentacles?

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

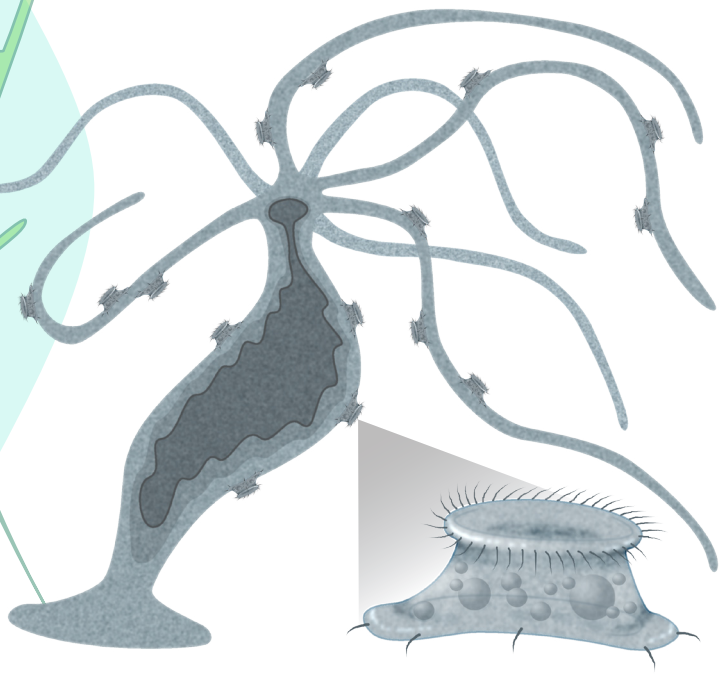
Day 10: 11:30 hours... Hiding beneath a giant aquatic plant leaf we observe the hydra, now safely beyond the reach of its tentacles. There is so much we do not know about this monster. We may not have another opportunity like this one for detailed observation.

Closer magnification through my telescope reveals some unusual movement on the creature's skin. Then we see it – single-celled organisms cover the hydra!

These disc-shaped single-celled organisms are ciliates, adapted for living on the surface of the hydra. They use their cilia to make feeding currents for pulling in bits of food, and for walking and hanging onto the hydra.

We have a theory that these single-celled partners scavenge bits of food captured by the hydra. This helps to keep the monster free of pesky bacteria. In exchange, the hydra provides its tiny guests a home safe from other predators.

How, we wonder, does a baby hydra become home to these partners? Which begs the question: where do baby hydras come from?



A Quiet Feeding Frenzy

A cloths-hanger/stocking net swept through the pond weeds will often capture great numbers of *Daphnia* and other small crustaceans — dinners for hydra! Add a few *Daphnia* and observe with these questions in mind:

- How does hydra capture its prey?
- Does it paralyze its victim before swallowing?
- How long does digestion take?
- What happens to the undigested portion of the meal?

Cloning New Hydras by Budding

Hydras reproduce by **budding**. In the days following a large meal, you might discover how hydra reproduces by budding from a new individual, and how long the process takes.

EXPLORATION GUIDE & JOURNAL

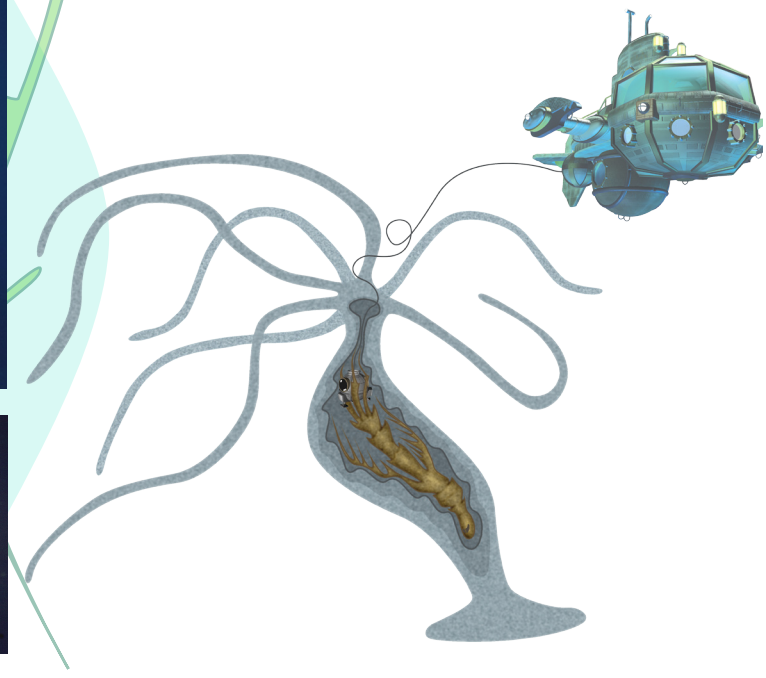
The Log of Captain Jonathan Adler

12:15 hours... What luck! We have just seen a nearby hydra capture a copepod. The unfortunate copepod struggles for a moment, then becomes still. Lyra believes that the hydra's tentacles have a stunning effect on the copepod – stinging cells! We believe that these stinging cells inject the captured animal with a paralyzing agent. When it is immobile, the hydra devours the prey alive.

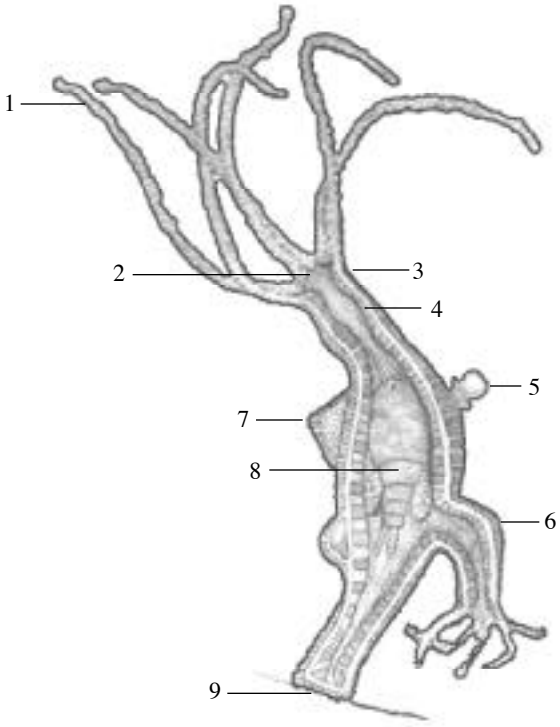
Lyra suggests a bold mission! She wants to use our diving bell to observe how the hydra digests its copepod dinner. The diving bell is a sturdy vessel, so I grant permission for this bold venture.

13:00 hours... The diving bell is now inside the hydra's gut! Lyra observes that acid is building up quickly around the captured copepod. She believes that the hydra's stomach lining excretes the acid, which digests the meal. But the copepod's protective shell is indigestable. How does hydra manage the indigestable parts?

The chemical alarm rings in the diving bell! The hydra's stomach acid is beginning to dissolve the bell's hatch seals – and if it does, it will digest Lyra as well! We try, but are unable to pull the diving bell out of the hydra. Then finally, the hydra spits out the shell of the copepod and my ship's naturalist with it.



Key to Organism



Hydra

1. tentacles with stinging cells
2. mouth
3. epidermis
4. gastrodermis
5. female reproductive parts
6. bud
7. male reproductive parts
8. copepod undergoing digestion
9. basal disc

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MICROSCOPIC MONSTERS

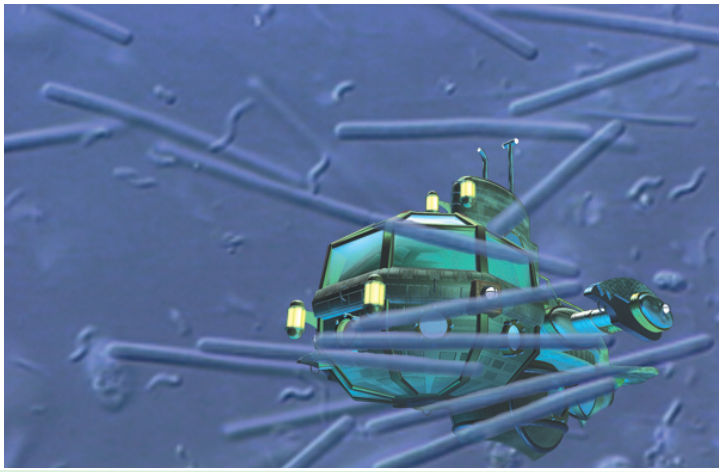
Accompanies Episode 5 of the 13-part video series

The Bacterium that Came to Dinner

Written by Eric R Russell & Bruce J Russell

In this episode...

When the Cyclops crashes into the pond bottom the crew discovers that the bottom ooze is populated by bacteria, thousands per cubic millimeter. They capture a bacterium and investigate the chemical methods it uses to decompose organic material—digestive enzymes secreted through tiny pores in its outer covering. The species they capture produces alcohol as a waste product, which the crew can use to improve the efficiency of the ship's engine.



EXPLORATION GUIDE & JOURNAL

Pond Ecology: Bottom Ooze

The Log of Captain Jonathan Adler

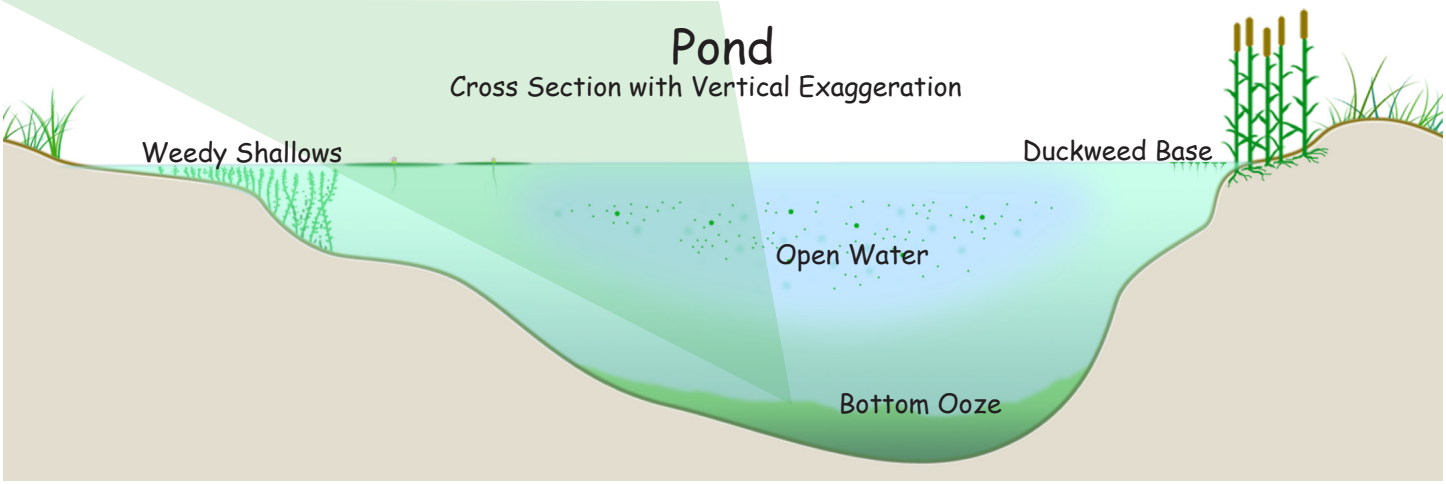
Day 11: 11:00 hours... We have at last made our way clear of the treacherous weedy shallows and are now making our way back toward Duckweed Base.

Our helmsman, Gyro, adjusts our course to steer clear of the pond lilies. I am concerned that there may be microscopic predators on the underside of these massive plants. I would be most pleased to avoid further adventures with predators.

12:25 hours... An alarming metallic SNAP echoes through the hull!

Gyro reports that a control cable connecting the helm to the ship's control planes has broken. The Cyclops is diving toward the pond bottom out of control!

Down, down we go, accelerating! I shout the order to brace for impact. I can only hope that we are not dashed to bits...



MS Cyclops

Vehicle Dimensions

LENGTH	1 mm
BEAM	.65 mm

Vehicle Mission

Maximum speed	10 centimeters per minute
Maximum depth	2.5 meters
Mission duration	60 days

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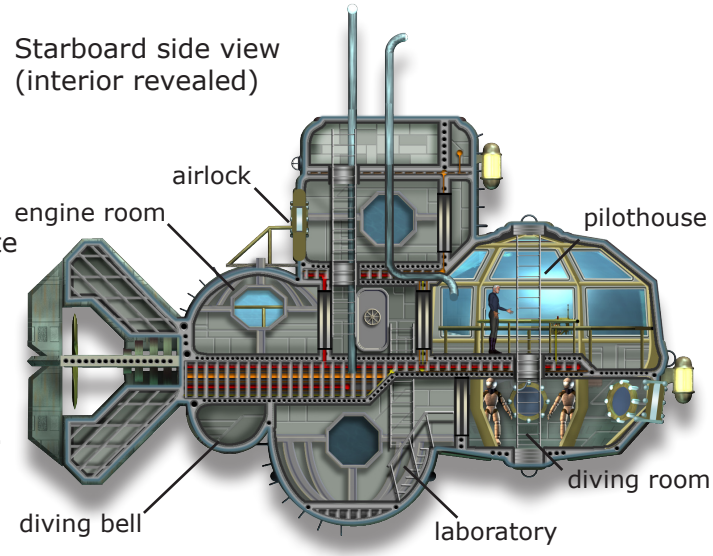
The glass enclosed pilothouse is a unique feature that allows for optimal observation of the surrounding aquatic environment.

Manipulator grabbers (claws) facilitate rapid making-fast and retrieving samples for study.

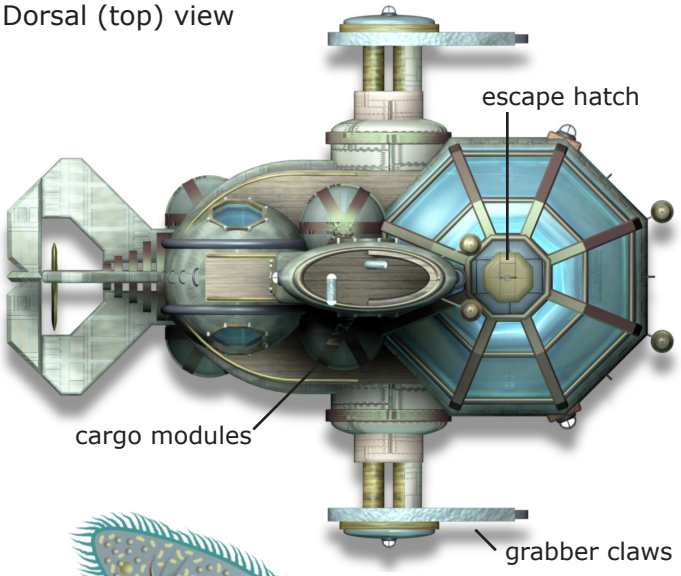
What if you were a scientist onboard the *Cyclops*? Imagine what the pond environment looks like to these micro sized explorers, only 50 microns (*μm)* tall. What unique problems might they encounter because of their size? How would they acquire repair materials, such as glass? Where would they find food, fuel, or oxygen?

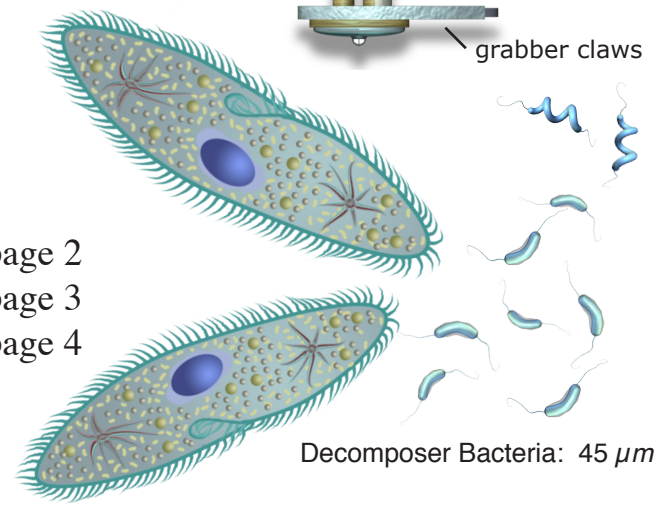
Starboard side view
(interior revealed)



Micro Submersible Cyclops: 1000 *μm*

Dorsal (top) view





Decomposer Bacteria: 45 *μm*

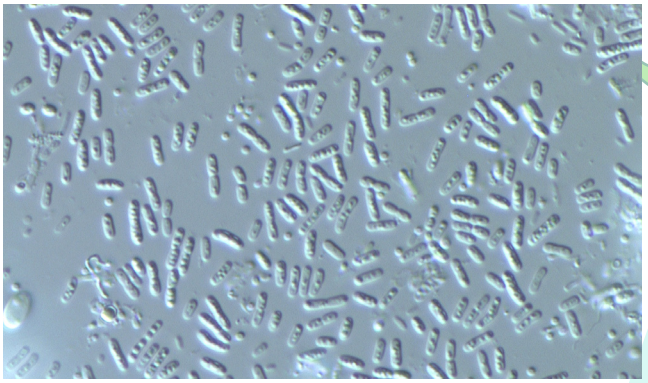
Paramecium: 500 *μm*

Contents of this guide...

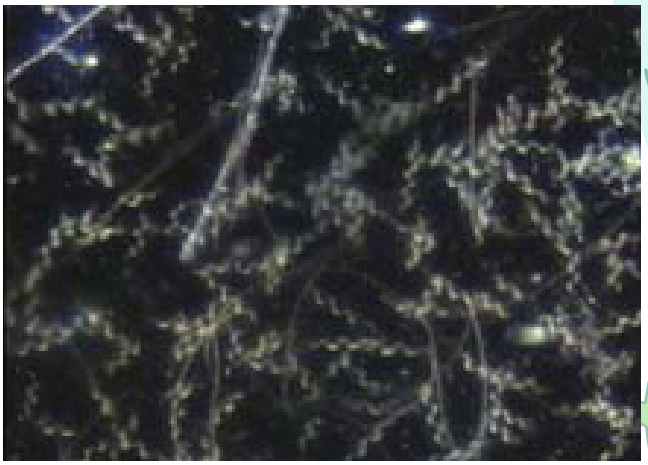
About the Organism

Pond Bacteria

The layer of loose organic material covering a pond bottom is swarming with life. This **bottom ooze** is where dead organisms are broken down and their vital elements recycled for use by living ones. This task is done by bacteria, including some of the largest and most interesting representatives of these tiny cells.



Decomposer bacteria secrete **digestive enzymes** into their environment. The enzymes process dead organic material, breaking it down into simple **building-block molecules**. Bacteria absorb these building blocks and use them for energy and building new bacterial **proteins**, **fats**, **carbohydrates** and **nucleic acids.**



Bacteria become food for bacteria-feeding protists such as *Paramecium*, beginning a **food chain** based on decomposition.

Bacteria are the most abundant and diverse organisms on Earth. They thrive in ponds and wetlands, in the soil, and in every kind of animal, plant, and fungi.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

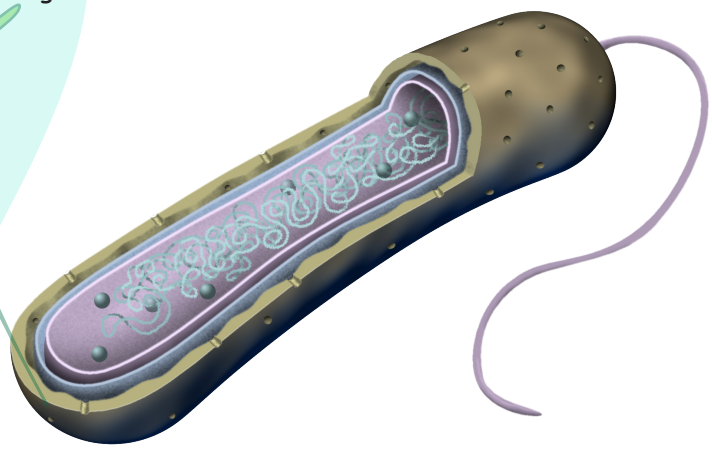
13:30 hours... Luckily, the pond bottom turns out to be softer than suspected. We survive our ungraceful landing with only minor damage. While engine master Barron begins repairs to the Cyclops, Lyra and I sample the conditions here on the bottom. The water down here, we quickly learn, is lower in oxygen than near the surface. And the carbon dioxide levels much higher. We wonder what would account for such conditions?

When we take a peek outside we see a world swarming with bacteria! As usual, Lyra insists that we bring one of these small cells onboard for closer study.

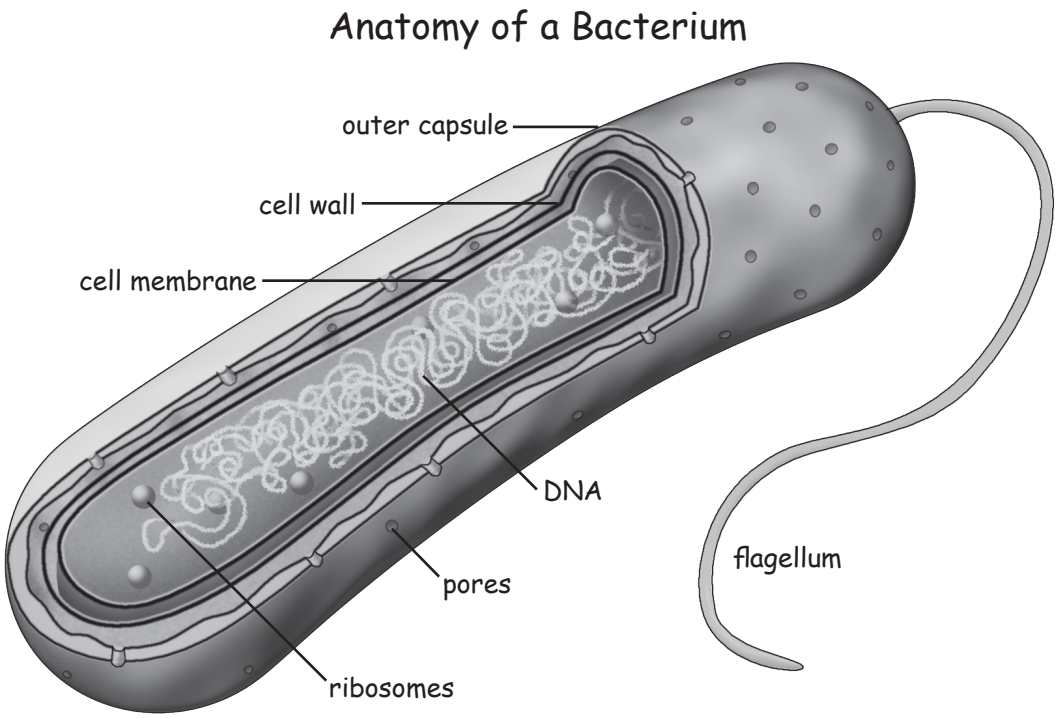
14:10 hours... The bacterium we capture appears much simpler than our previously studied microorganisms. Unlike the larger single cells we've encountered it has no nucleus, and very few internal parts.

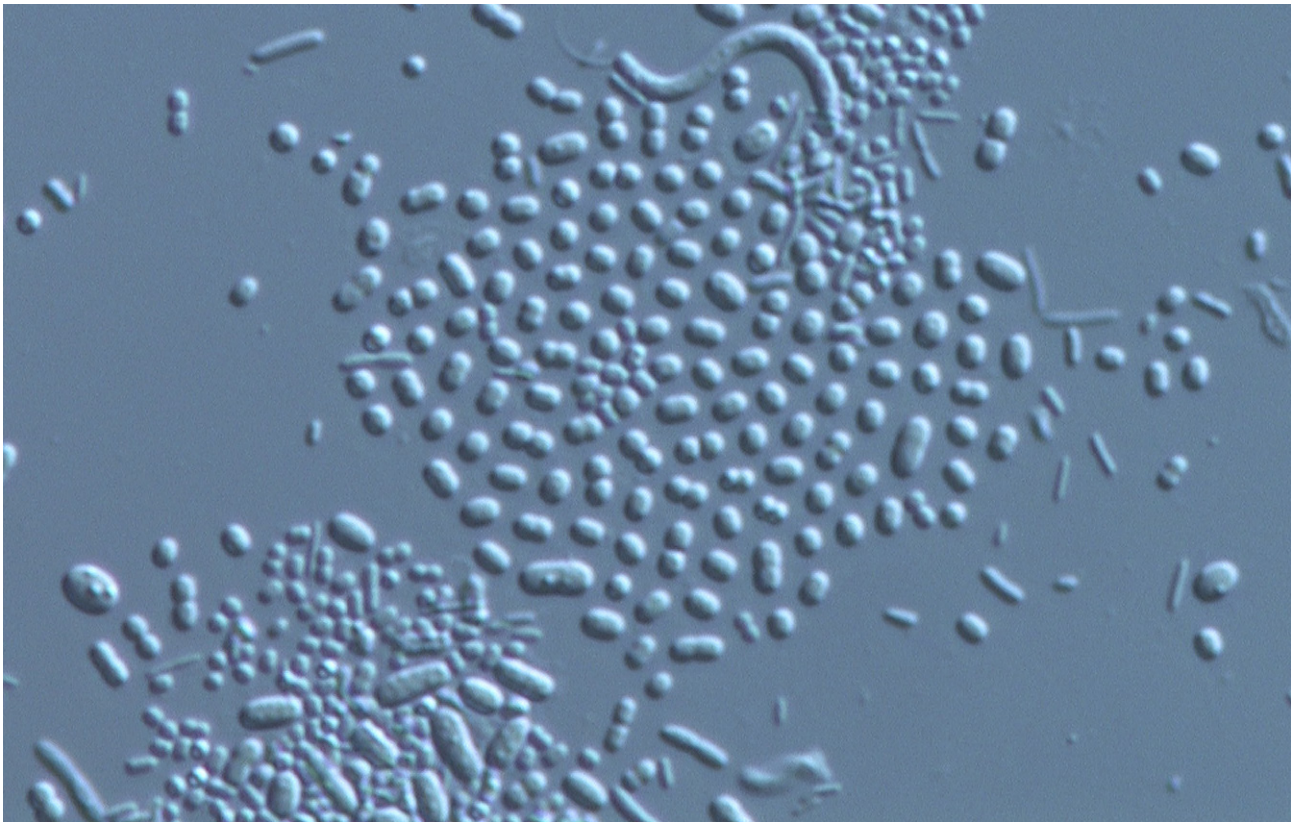
To our astonishment the bacterium has a destructive effect on our examination pool! A closer look shows that the bacterium fills the surrounding water with digestive molecules called enzymes. These enzymes react with dead plants and animals, breaking them down into molecules that the bacterium can use to build more enzymes and other molecules of life.

We conclude that bacteria provide perhaps the most important role in Life – they break down dead organisms, then become food for larger single cells. And those become food for larger organisms yet. This is the beginning of a **food chain.**



Key to Organism





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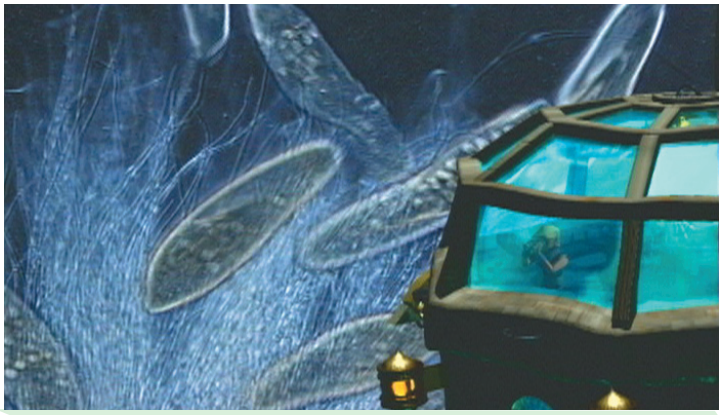
Accompanies Episode 6 of the 13-part video series

Voyage to the Bottom of the Food Chain

Written by Eric R Russell & Bruce J Russell

In this episode...

While exploring the dark pond bottom, the *Cyclops* crew continues to observe a variety of bacteria. They discover that these bacteria are the food of choice for large single celled protists, in this case... a group of paramecia. Food chains can begin with **decomposers**, like bacteria, or **producers**, like photosynthetic plant and algae cells. Then they encounter a second group feeding on green algae cells, and use the opportunity to study *Paramecium's* feeding and digestion up close... until they learn what in fact feeds on *Paramecium*.



EXPLORATION GUIDE & JOURNAL

Pond Ecology: Bottom Ooze

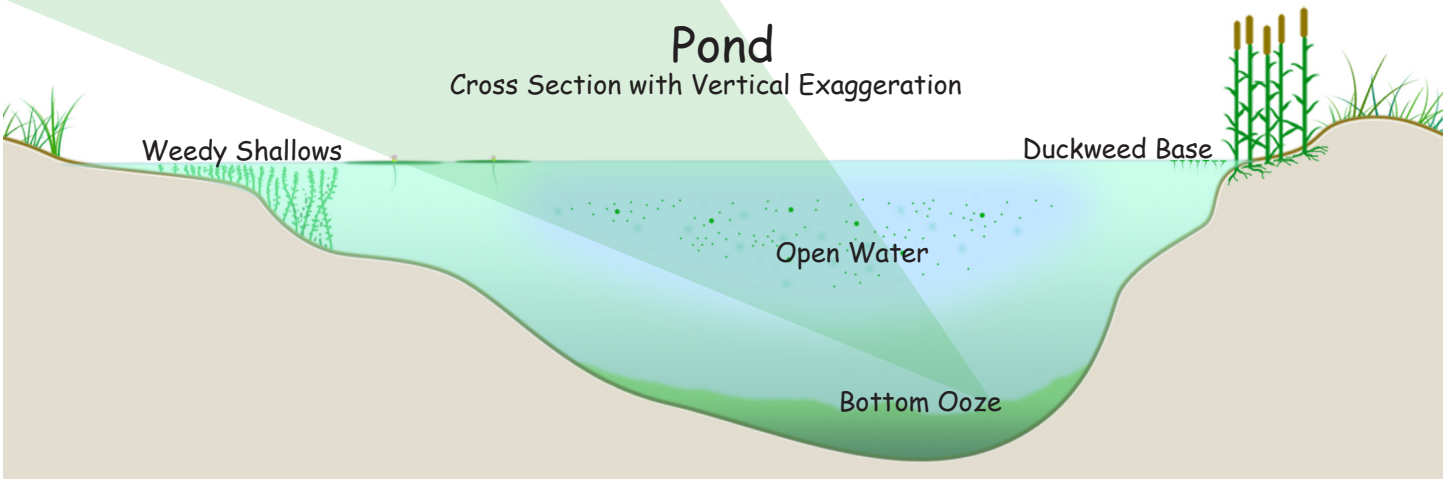
The Log of Captain Jonathan Adler

Day 12: 08:00 hours... Outside, the pond bottom drifts eerily past our windows. Surrounding the Cyclops is a murky world of darkness made up of rotting pond plants and microorganisms. This is the graveyard of the pond – where all pond organisms fall to rest when life ends. And yet, this is where life begins again! All thanks to bacteria.

They are everywhere! Some are short rods – others long ones. Or spring-shaped spirals. Or chains of small round beads. Or hair-like strands. We cannot count or classify the many species that thrive here on the pond bottom, breaking down dead organisms and absorbing the important chemicals needed for life. This is the beginning of a **food chain**.

Through the darkness we see larger shapes. Predators? Scavengers? I turn up the lamps...

Paramecium has arrived. Many large single celled organisms are feasting on the bottom-dwelling bacteria, gorging themselves as fast as they can – and there are plenty of bacteria to go around!



MS Cyclops

Vehicle Dimensions

LENGTH	1 mm
BEAM	.65 mm

Vehicle Mission

Maximum speed	10 centimeters per minute
Maximum depth	2.5 meters
Mission duration	60 days

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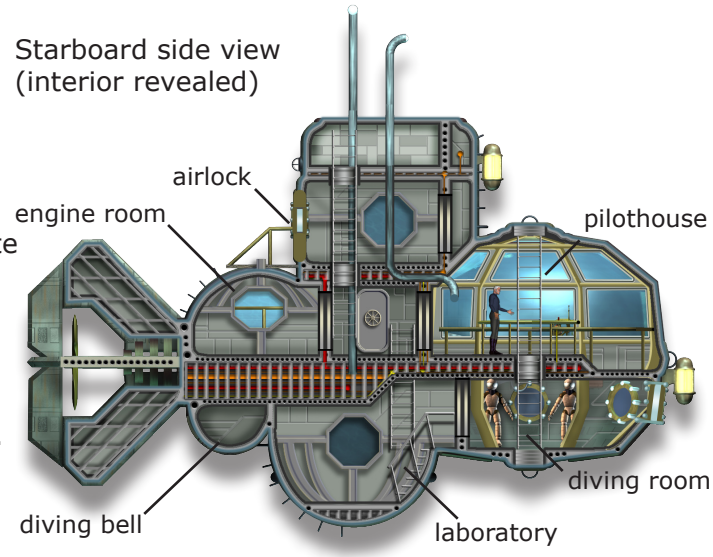
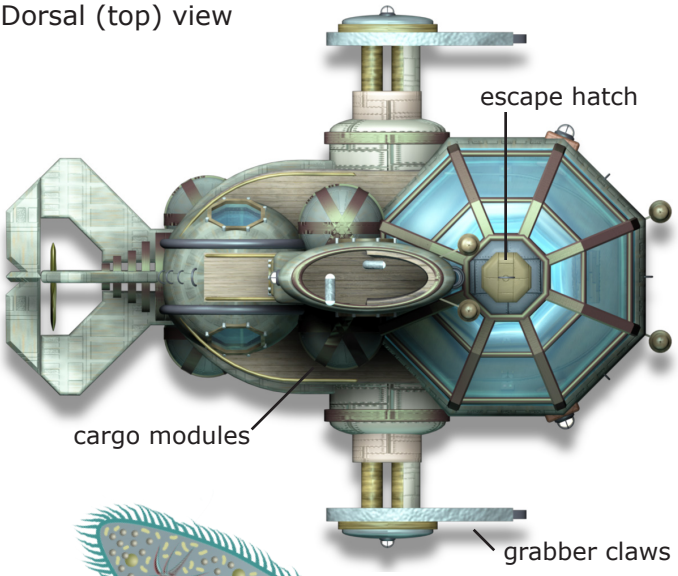
Starboard side view
(interior revealed)

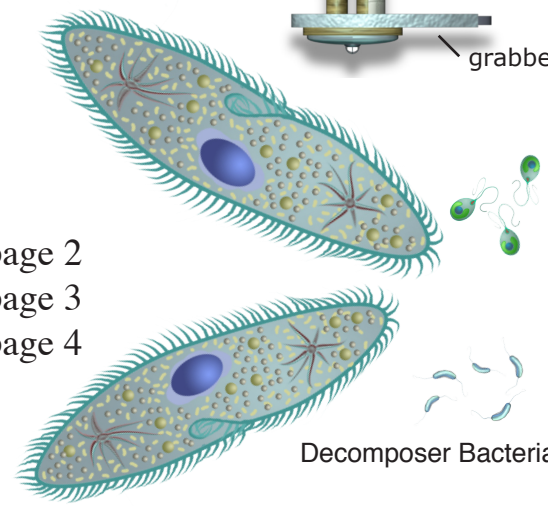


Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



Contents of this guide...



Decomposer Bacteria: 45 *µm*

Paramecium: 500 *µm*

About Food Chains

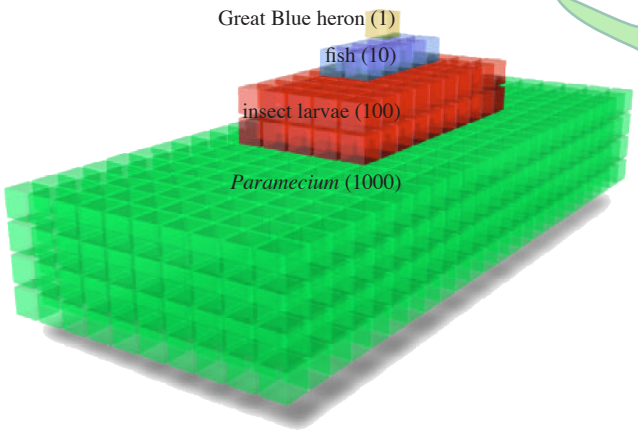
In ponds, algae cells are food for all sorts of small animals and protists. The algae cells make their own food by *converting sunlight and carbon dioxide into starch for energy.* This is how a **food chain** begins with **photosynthesis**.

A **food chain** can also begin with **decomposition**. Dead organisms and waste material fall to the pond bottom where they are digested by bacteria. Bacteria are eaten by protozoans. The protozoans are eaten by small water animals and so on.

In this episode the crew observes *both* beginnings of a food chain. First, they see *Paramecium* devouring bacteria. Later they witness an attack by *Paramecium* and other ciliated protists on a swarm of small green cells. The abundant green cells create an unusual feeding opportunity for *Paramecium*, which usually subsists on a bacteria diet. The paramecia, in turn, become food for small pond animals such as baby fish, mosquito larvae, water worms, and colonies of filterfeeding animals known as bryozoans – the colony seen at the end of the episode.

Advanced Food Chains Facts: At each step in a food chain, only part of the energy contained in the organism being eaten is stored in the cells and tissues of the eater. A rough rule is that only about 10% of the energy moves from one food chain step to the next. In this food chain a heron eats fish, fish eats mosquito larva, mosquito larva eats *Paramecium*, *Paramecium* eats single cell green alga and bacteria.

Energy Pyramid of a Food Chain



EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

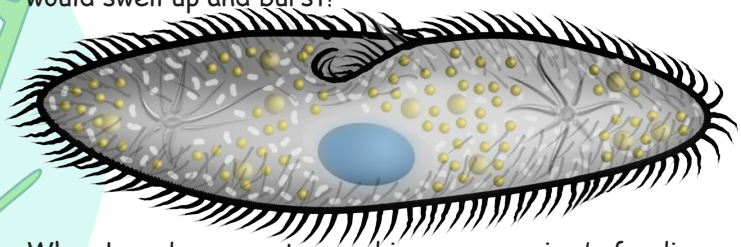
10:40 hours... Because the paramecia are holding relatively still to feed on the bacteria, we have an excellent opportunity to observe the large protists up close. Their internal **organelles** are quite easy to see.

- A bluish central nucleus
- A pulsing star-shaped water pump at each end
- A groove-like mouth that turns into digestive sacs filled with captured bacteria.
- An outer surface covered with a thick coat of waving cilia.

We learn that a paramecium uses its cilia in several ways: to move about its environment both forward and backward, to create a feeding current of water that draws in food, to hold itself in a "feeding station" where it can easily suck in large amounts of food organisms.

Lyra observes that when a paramecium eats, some parts of bacteria and green algae cells are not digestible. They must be expelled by the paramecium.

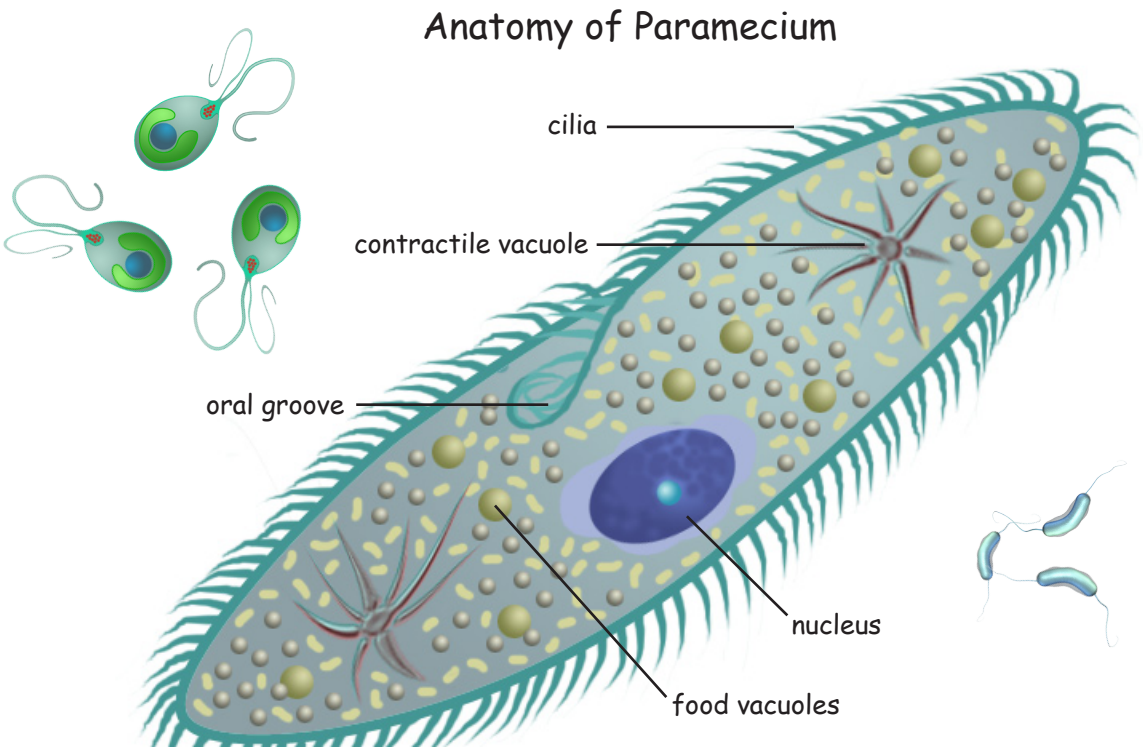
Water enters the paramecium constantly, but we observe that the cell has an way to pump water back into the environment – two pumps, one located at each end of the paramecium. If it were not for these pumps, the cell would swell up and burst!

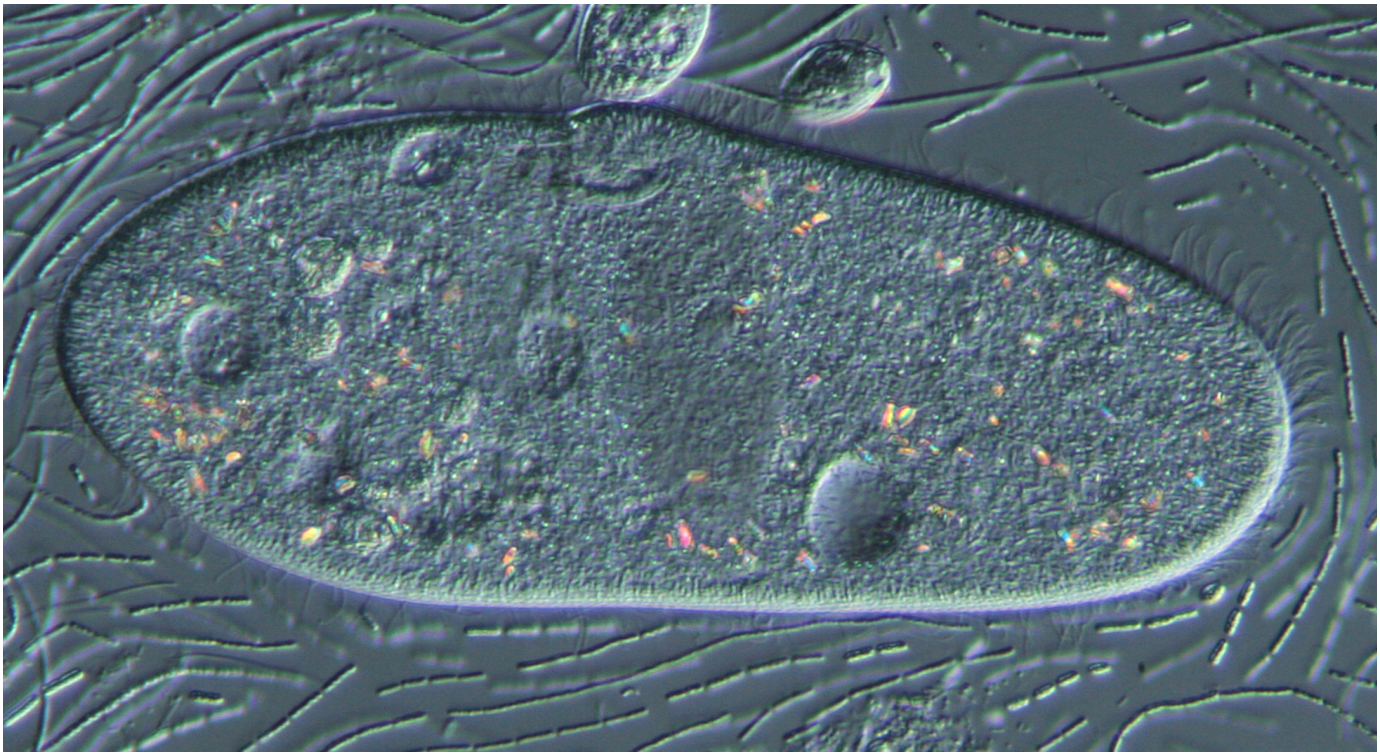


When Lyra becomes trapped in a paramecium's feeding current we must act quickly to distract the cell. We know that paramecia are attracted to bacteria by the carbon dioxide that bacteria give off. Quickly, Barron releases the contents of the Cyclops' carbon dioxide holding tanks, which lures the paramecium away, allowing Lyra to escape – once again.

As we continue our voyage, we look back to see a large colony animal feeding on the paramecia we were observing only moments ago. It seems that in the food chain of the micro world, there is always a bigger monster!

Key to Organism





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Accompanies Episode 7 of the 13-part video series

Quick Current Critters

Written by Eric R Russell & Bruce J Russell

In this episode...

En route to Duckweed Base, the *Cyclops* and crew are Sucked into the pond outlet, where they are washed out of the pond and tumble into a rapidly flowing stream. In the rapids they discover a world of aquatic insects living under the algae coated rocks. Careful observation reveals that insects are marvelously adapted for living on water-swept rocks. They use hooks, streamlined shapes, suckers and safety lines—adaptations that allow these aquatic insects to exploit this hazardous habitat free from large predators and other organisms that might compete for food.

Stream Ecology: The Rapids

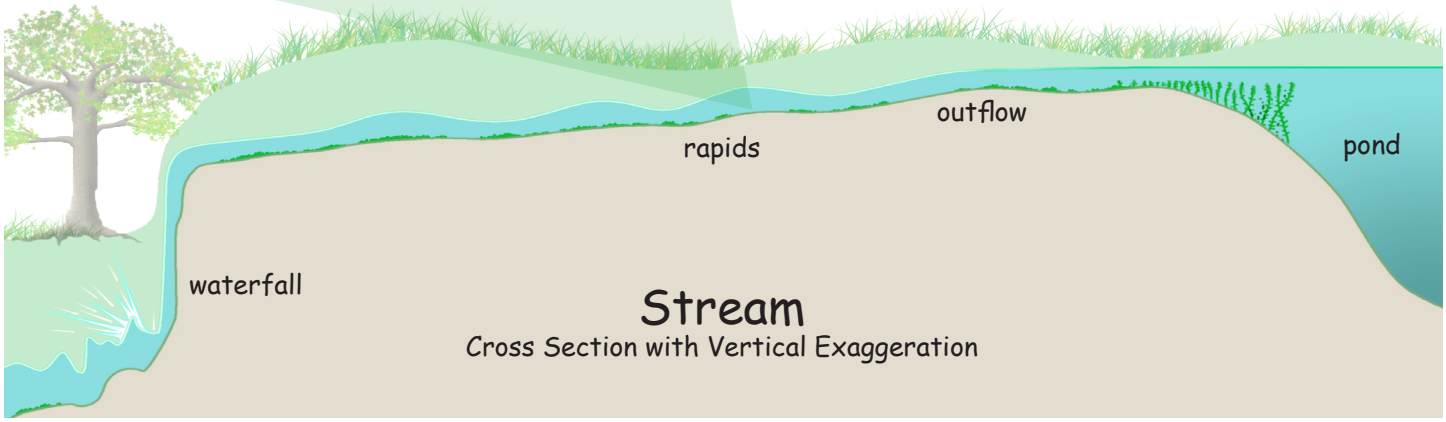
The Log of Captain Jonathan Adler

Day 13: 09:45 hours... It must have rained last night. We awoke this morning to cooler water.

This is a very exciting day for us! Gyro reports that we are on schedule to arrive home at Duckweed Base before noon. All aboard are excited with the prospect of several days of rest and relaxation before continuing on with our biological survey mission. The crew has performed quite well on this first voyage. My report to the Micro Exploration Institute will praise these courageous explorers, and I will be recommending promotions for everyone.

10:15 hours... Gyro reports a concern. He is feeling a bit of a cross current against the wheel. To my distress the current increases with each passing minute. I can only guess that the rain in the night has flooded the pond, and that we have encountered an uncharted outflow current. Barron reports from the engine room that we don't have enough power to escape the current.

A moment later my fears are confirmed. We are being swept out of the pond, powerless and out of control!



Stream

Cross Section with Vertical Exaggeration

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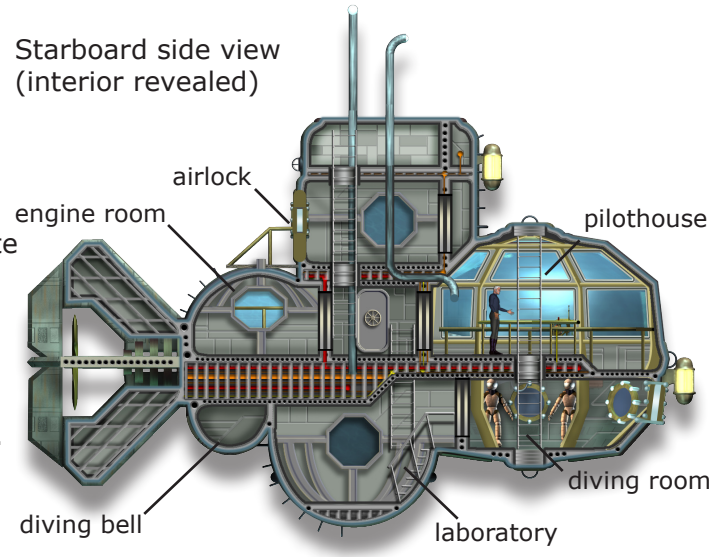
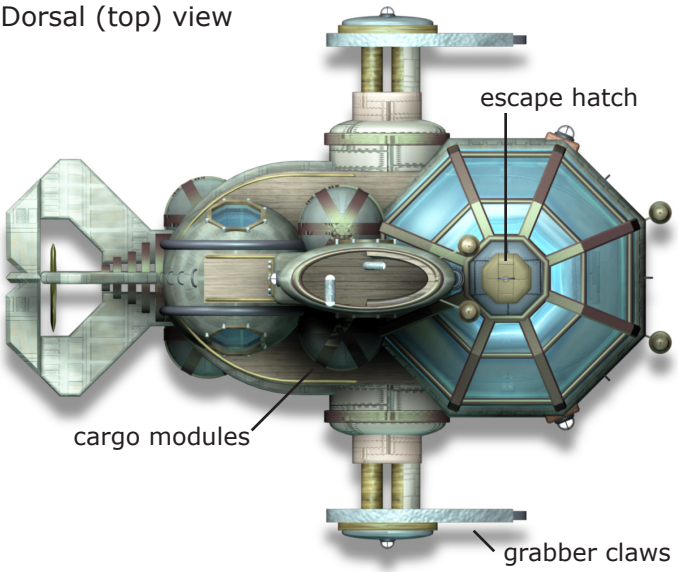


Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



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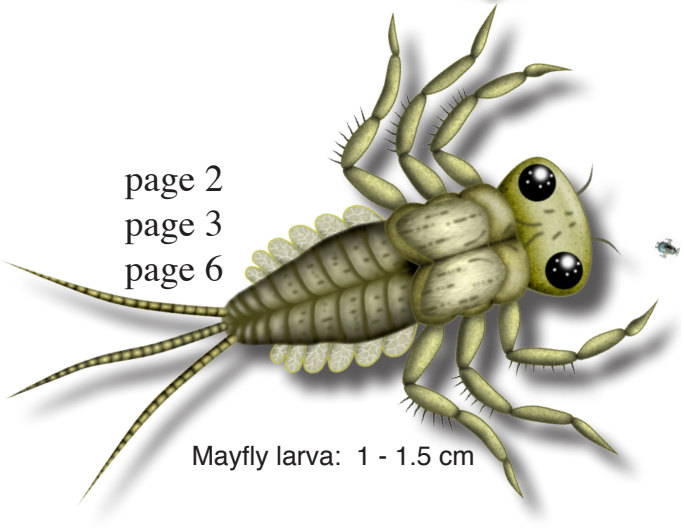


Mayfly larva: 1 - 1.5 cm

About the Organisms

Mayfly Larvae: The larval stage of mayflies are adapted for life under rocks and for dealing with rapid stream current.

Look for:
- flattened bodies and appendages
- mouth parts adapted for scraping algae from the rocks
- rows of leaf-like gills along their abdomens

A mayfly's circulatory fluid is pumped through branching vessels in each gill. The gills can be fanned to improve extracting oxygen from water. This also helps flush carbon dioxide.

larval mayfly

The adult mayflies are short-lived, some only live for a day. They mate and lay their eggs in the stream. Mayfly larvae are preferred snacks for hungry trout.

adult mayfly

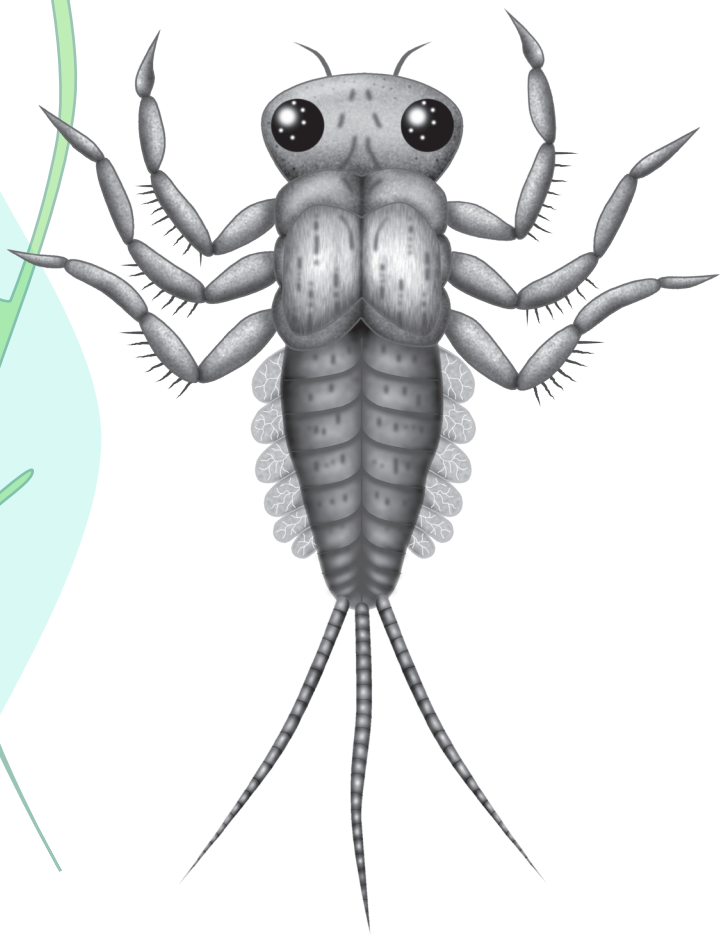
EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

10:20 hours... we are caught in the rapids!

Enormous stream rocks streak past the windows as the current whisks the Cyclops downstream. Our friends at Duckweed Base will worry when we are overdue. I am hoping that they send out a scout to find us. In the hopes that they do, I order the crew to shoot a signal flare. Maybe somebody will see it!

When we gain control of the ship again we are stunned by the presence of many animals crawling around the stream rocks. They all have hard shell-like coverings, bodies in three sections, and six legs – they are insects! Because they are living in water, we must be seeing the larval stage of an adult insect that normally lives above water, in the air or on the land.



About the Organisms

Caddisfly larvae: They look like moving sticks, or little tubes made of sand grains. Caddisfly larvae cement these protective homes together as they grow. Like mayflies, they harvest algae attached to the rocks.

Stonefly larvae: Stoneflies are usually found living underneath stream rocks where they prey on mayflies, capturing them with their sharp mandibles. They are one of the largest stream insects and a favorite food of trout. If conditions become stagnant, stonefly larvae will begin doing "push-ups." This behavior helps circulate water over the tufts of gill filaments located at the base of each leg. The adult stonefly looks much like the larva, but with leathery wings.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

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Enormous stream rocks streak past the windows as the current whisks the Cyclops downstream. Our friends at Duckweed Base will worry when we are overdue. I am hoping that they send out a scout to find us. In the hopes that they do, I order the crew to shoot a signal flare. Maybe somebody will see it!

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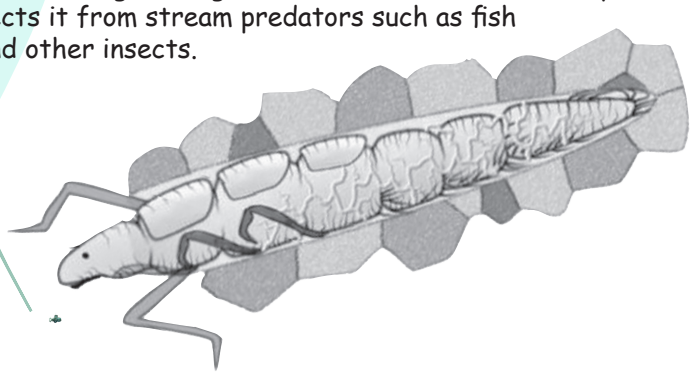
One type of insect, mayfly larvae, have flattened bodies for living on the rocks without being whisked downstream by the powerful current. Their streamlined bodies and hooked feet allow mayflies to crawl over stream-swept rocks, scouring the surfaces for food. But what are they eating? A close look at the surface of a sunlit rock reveals the answer. Diatoms – just like the ones we found living in the pond! These photosynthetic algae cells cover the rocks, and provide food for the mayflies.

12:35 hours... further downstream we see a jumble of sand grains moving about! A closer peek shows that this pile of sand grains is a house for another type of stream insect. A caddisfly larva. Some caddisflies build houses from sand grains, others from small sticks. The insect's head and legs emerge from a tube-like house that protects it from stream predators such as fish and other insects.



Water tigers: These are the larval stages of diving beetles. The one shown is *Dytiscus*, the giant water beetle. *Dytiscus* larva are surface breathers, periodically poking their tails through the surface to take in air.

The water tiger feeding method is fascinating (and a little horrifying) to observe. They attack fish and tadpoles, spearing their prey with rapier-like mandibles. The mandibles are hollow and there is no mouth. After injecting digestive enzymes into the prey, *Dytiscus* reverses its pump and sucks up the partially digested content.

larval Dytiscus

Care should be taken when handling water tigers as the mandibles of a large specimen are capable of piercing the soft parts of hands and fingers.

adult Dytiscus

The Log of Captain Jonathan Adler

13:20 hours... swept into a slow moving pool, we see a savage monster of the stream insect world.

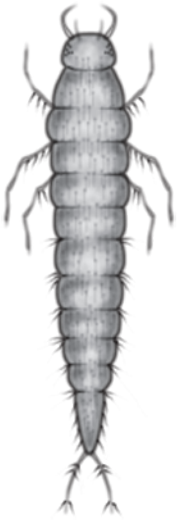
This very large insect larva goes by the well-earned name of water tiger! It is a fierce predator, as we soon observe.

The water tiger attacks a tadpole. Its long, needle-sharp fangs pierce the poor pollywog, which quickly becomes still.

We believe that the water tiger injects some kind of toxin into the tadpole, paralyzing it, and turning the internal organs into soup.

After a minute a ghastly feast begins. Through its fangs the water tiger begins sucking in the tadpole's liquified insides. What a surprise, to find an insect that preys upon more complex animals. Tadpoles and small fish are no match for the fearsome water tiger!

Although we are most likely too small to grab its attention, we steer clear of the feasting water tiger and continue our white water journey down the stream.

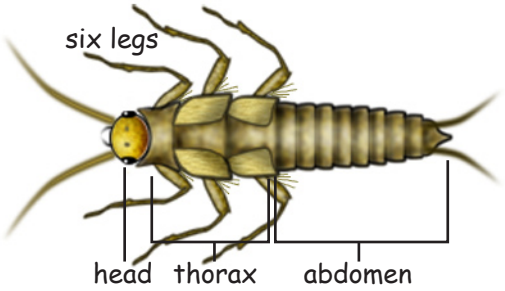


Key to Organisms

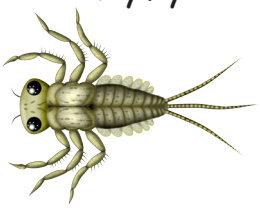
The Insect Body Plan

All insects have bodies in three sections: **head, thorax**, and **abdomen**. The **head** contains eyes, brain, mouth, and antennae. The **thorax** is where legs and wings attach. The **abdomen** has reproductive organs and the intestine. Insect larvae and the adults they become have the same body plan. Wings do not fully develop until the insect emerges from a pupa and begins life above the water.

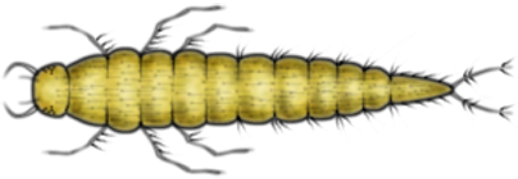
Stonefly



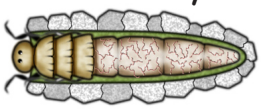
Mayfly



Water tiger



Caddisfly



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Accompanies Episode 8 of the 13-part video series

Down the Waterfall

Written by Eric R Russell & Bruce J Russell

In this episode...

Carried by the current, the *Cyclops* and her crew continue their journey down a rocky stream. As they drift ever closer to a waterfall they come across a colony of **blackfly** larvae thriving in a fast skim of water barely an inch deep. When the *Cyclops* is swept over the waterfall they find themselves trapped inside a plastic bottle, which turns out to be the ideal place to observe one of the strangest aquatic insects inhabiting the white-water... a **water penny**.

EXPLORATION GUIDE & JOURNAL

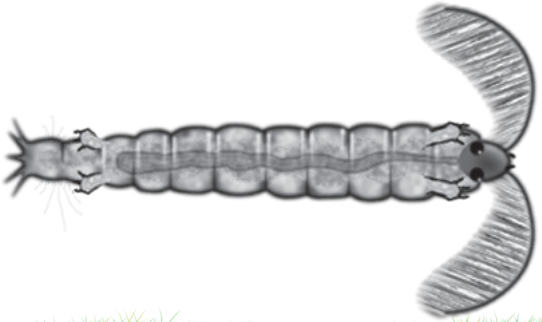
Stream Ecology: Waterfall

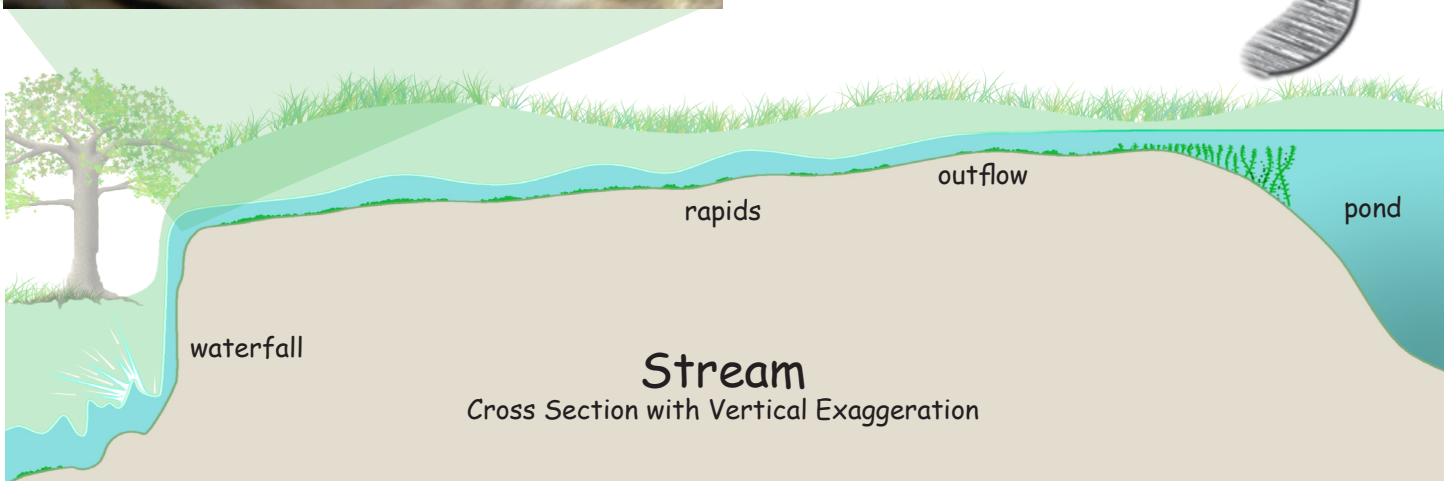
The Log of Captain Jonathan Adler

Day 14: 08:25 hours... It is our second day of unplanned exploration down a fast-flowing rocky stream. The view outside our windows is a rapid blur of white water bubbles and rocky stream bottom.

The speed of the current increases. I can see that we are being swept over a shallow flat surface, probably a stream-worm sheet of granite. And we are not alone!

Anchoring ourselves we get an outstanding view of the insects living here in the fast water. The smooth rock surface is crowded with hundreds of blackfly larvae. A blackfly's tube-like body sticks up into the current, gripping the rock with a claw-like foot pad. From the head end, the larva extends feather-like fans that catch tiny bits of food drifting by in the current.





Stream

Cross Section with Vertical Exaggeration

MS Cyclops

Vehicle Dimensions

LENGTH	1 mm
BEAM	.65 mm

Vehicle Mission

Maximum speed	10 centimeters per minute
Maximum depth	2.5 meters
Mission duration	60 days

The microsubmersible *Cyclops* is designed for extended exploration of freshwater ponds, streams, and wetlands. The vehicle carries a standard crew of four.

- Captain
- Ship's Naturalist
- Helmsman/Navigator
- Engine Master

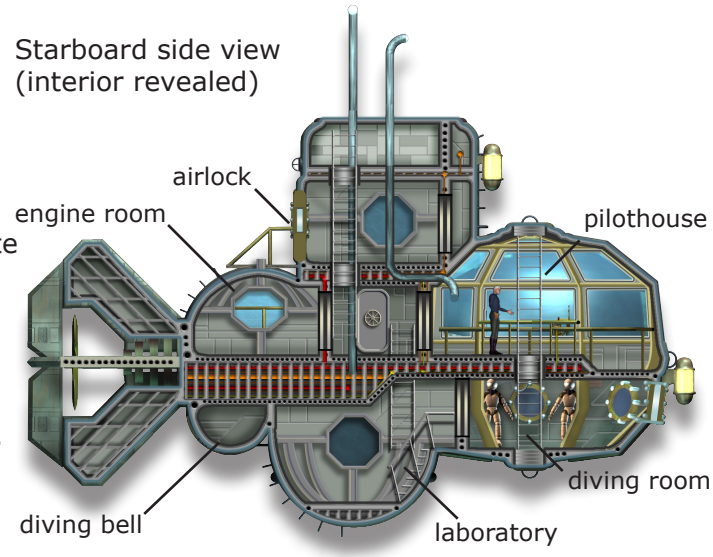
There are two onboard auxilary craft for specialized exploration: a *diving bell*, and a terrestrial *crawler/rover* (disassembled).

The glass enclosed pilothouse is a unique feature that allows for optimal observation of the surrounding aquatic environment.

Manipulator grabbers (claws) facilitate rapid making-fast and retrieving samples for study.

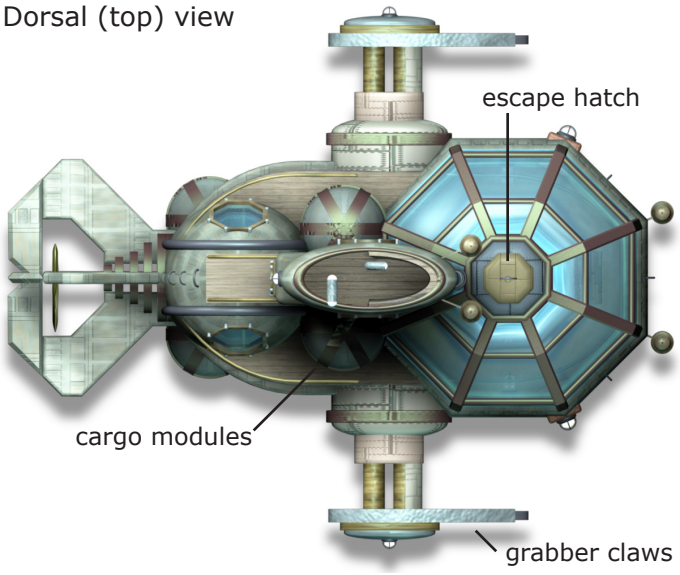
What if you were a scientist onboard the *Cyclops*? Imagine what the pond environment looks like to these micro sized explorers, only 50 microns (*µm)* tall. What unique problems might they encounter because of their size? How would they acquire repair materials, such as glass? Where would they find food, fuel, or oxygen?

Starboard side view
(interior revealed)



Micro Submersible Cyclops: 1000 *µm*

Dorsal (top) view



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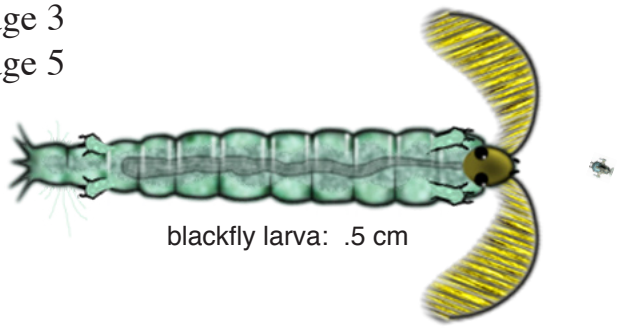


blackfly larva: .5 cm

About the Organisms

Adaptation: Observing stream life reveals that by living in extreme conditions a species can avoid competition for food resources and avoid being eaten by predators. To do this, however, the insect needs to be equipped for hanging on. This helps explain the remarkable adaptations seen in the inhabitants of rapids and waterfalls.

Blackfly larvae: Great masses of these worm-like larvae are found where sheets of shallow water race over the stream rocks. A smooth flow with little turbulence is a requirement for the blackflies' feeding style. Holding to the rock with a sucker-like basal disc, they throw out fan-like filters that trap microorganisms and tiny bits of debris carried by the current. Periodically the filters are drawn through the mouth parts and cleaned of food. If disturbed the larva releases its hold on the rock and drops down stream by playing out a safety line. After things calm down, it climbs back up the line and reattaches to its feeding station.

As the stream level drops in summer the larvae pupate – that is, develop from larval stage into adult stage, just like a caterpillar becomes a butterfly. This leaves the pupa exposed to air, which assures successful hatching of the adults.

Adult blackflies are bothersome parasites that feed on the blood of warm-blooded animals. The small adult black flies burrow into the animal's hair (or feathers), nip through the skin while bathing the wound with a anesthetic that deadens feeling.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

10:20 hours... We have observed that these blackfly larvae prefer life in one of the most demanding habitats of the stream. Their adaptations for survival allow them to live in a place without any competition for food! Another insect would be whisked away by the powerful current.

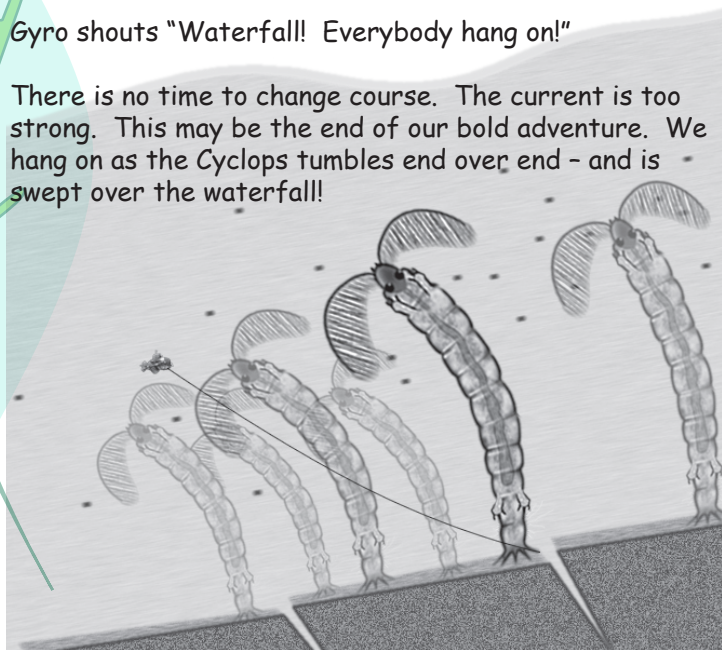
As microscopic algae and other tiny organisms drift down stream they are caught in a blackfly's food-gathering fans. Every few seconds, the larva gathers in the fans and devours the accumulated snacks. There is no hunting for this aquatic insect – it just waits for the food to drift into its trap.

If fish or large animals disturb the water around the blackflies, the larvae respond instantly by releasing their hold on the bottom. As the insects drift downstream, they let out safety lines. When the disturbance passes, the larvae crawl up the safety line and reattach themselves in the best location for gathering food.

11:50 hours... I have ordered the anchor stowed – the Cyclops is once again on an unknown course down the stream.

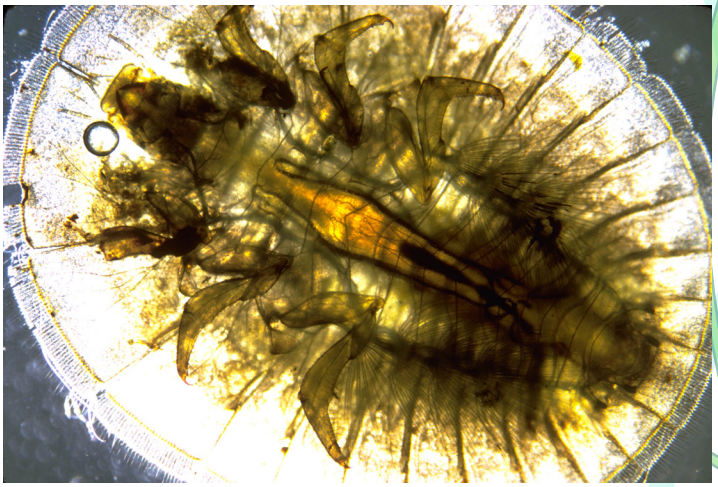
Gyro shouts "Waterfall! Everybody hang on!"

There is no time to change course. The current is too strong. This may be the end of our bold adventure. We hang on as the Cyclops tumbles end over end – and is swept over the waterfall!

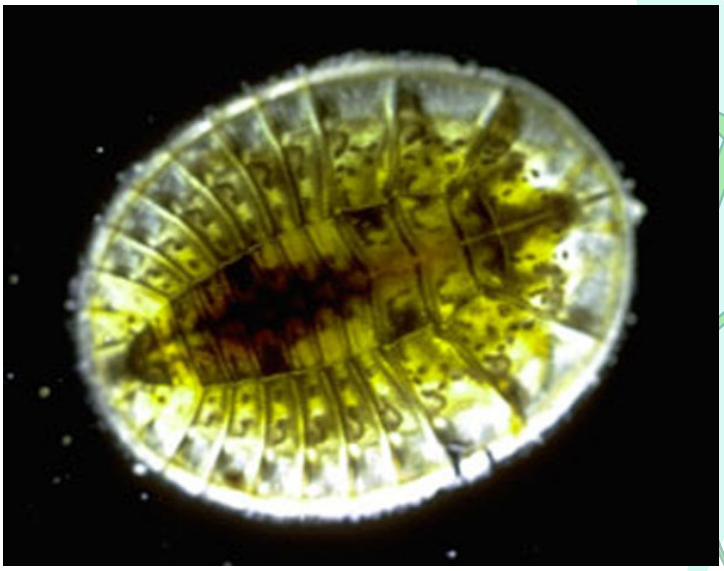


About the Organisms

Water Penny: This extremely flattened insect is the larval stage of a small aquatic beetle. Look for water pennies clinging to the rocks in stream rapids. Pressing one between two microscope slides allows viewing the insect from its underside.



This view shows the six sharp hooked feet that permit the water penny to hang on to the current-swept rocks, and the fringe of hairs around the outer shell that deflects the current, keeping it from getting under the insect and washing it away. Fluffy tufts of gills collect dissolved oxygen and help get rid of carbon dioxide. Under the microscope, the circulatory fluid can be seen coursing through the insect's flattened body.



In this view, you can see the stubby mandibles used for scraping algae from the rock.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

12:10 hours... We tumble through an explosion of thundering white water. I am certain that we will, at any moment, be smashed into the rocks. But that is not our fate!

Suddenly all is still. All is calm. But how? A look outside reveals that by pure luck the Cyclops has washed over the waterfall and into a discarded bottle! Clinging to the outside of our transparent refuge we see one of the strangest aquatic insects we have yet come across on our stream voyage – a water penny. The familiar insect body is protected by a flattened outer shell, a shape that is so perfectly streamlined that the fast current cannot wash the insect away. It appears to have found a perfect place on the bottle surface for scraping off algae for food!

14:15 hours... Just when we were beginning to worry that we might never escape from this plastic bottle sanctuary, a flicker of bright light from above the surface catches our attention. It is our companion Tara! She is focusing sunlight through a lens in our direction. Tara is trying to help us with our problem, but how can focusing sunlight free us from the bottle?

By using a mirror we redirect Tara's sunbeam through yet another lens. We focus the light into a very hot point at the bottom of the bottle. To our relief it works, and the plastic quickly melts. In no time we carve out an escape hatch. Not far from the waterfall the stream slows. We are able to navigate our way to shore where we reunite with Tara who is eager to expand our biological explorations into the nearby forest. It seems that the work of biological discovery is never done!

Key to Organisms

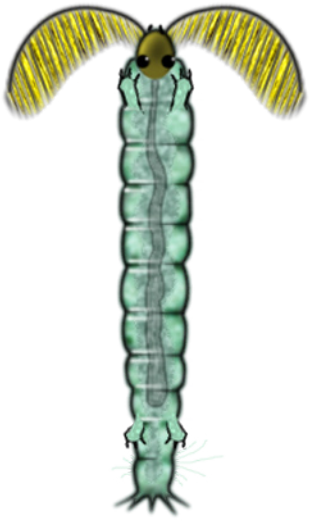
Different Adaptations

The blackfly larva and the water penny show two sets of very different adaptations for living in fast-moving water.

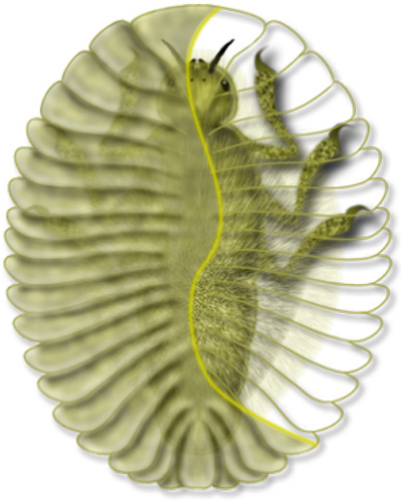
The **blackfly** sticks up into the current and uses fans to catch small food organisms as they drift by. If disturbed the insect lets go and washes downstream, letting out a safety-line filament. When the disturbance has passed, the blackfly uses the safety-line to crawl back to its ideal feeding spot in the current.

The **water penny** is almost perfectly flat, and clings so tightly to the rock that the current passes smoothly over its protective streamlined shell. Under the shell the insect scours the surface of the rock, scraping off algae with its sharp mandibles.

Blackfly



Water Penny



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Accompanies Episode 9 of the 13-part video series

EXPLORATION GUIDE & JOURNAL

Forest Floor Explore

Written by Eric R Russell & Bruce J Russell

In this episode...

Washed onto a sand bar to make repairs, the *Cyclops* crew assembles their *Terra Rover* and enters the forest on a new voyage of exploration. Traveling through the top inch of **humus** they discover that the soil is alive. This is a world dominated by **mites**, **roundworms**, tiny **insects**, **bacteria** and **fungi**. The living humus creates a diverse **forest floor ecosystem** on which the trees and larger forest organisms depend.

Forest Ecology: Forest Floor

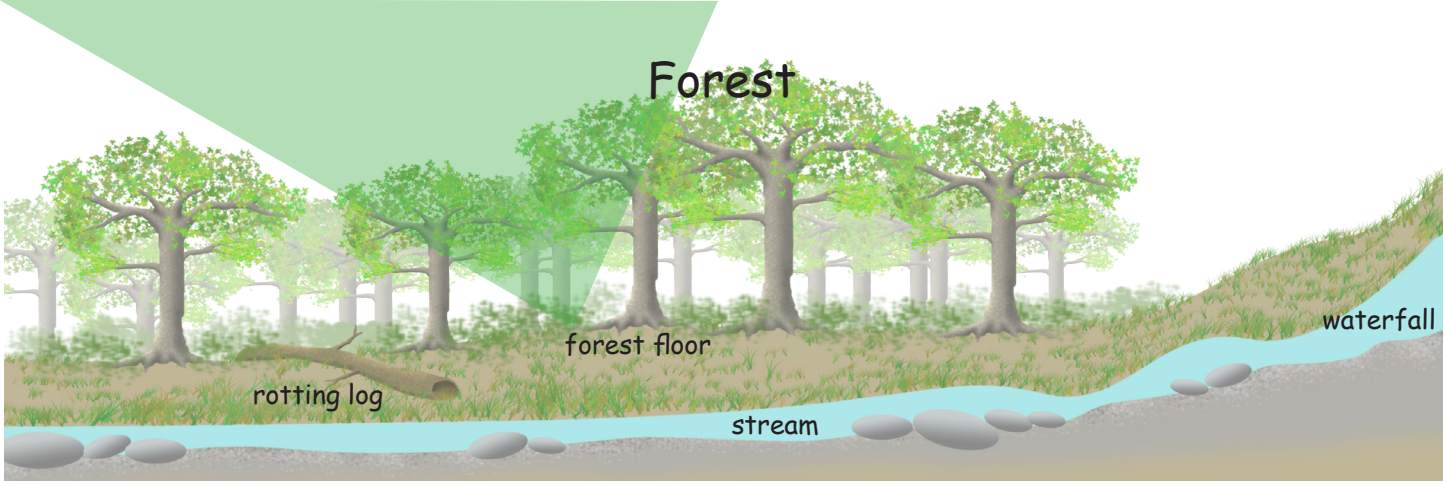
The Log of Captain Jonathan Adler

Day 15: 10:15 hours... After our adventure down the stream rapids, the Cyclops is in desperate need of repairs. I have ordered that the ship be secured along the shore so that my crew can begin the work.

Joining us is Tara, an explorer companion newly arrived from home base. Tara, also a naturalist, has an interest in the small life of terrestrial habitats. I am excited for this opportunity to explore the world of life on the land!

I have ordered the crew to assemble the rover so that while the Cyclops undergoes repairs Tara and I might journey into the nearby forest. We hope to discover what secrets lie in the upper levels of the soil, a region called the humus.

As the rover maneuvers through a dense mat of rotting leaves we can see layers of bacteria decomposing the dead plant cell tissue. This must be the beginning of the forest floor food chain!



Terra Rover

Terrestrial auxilary to MS Cyclops

Vehicle Dimensions

LENGTH	.35 mm
BEAM	.22 mm

Vehicle Mission

Maximum speed	3 cm per minute
Mission duration	10 days

The *Terra Rover* is a durable vehicle designed for exploration of terrestrial surfaces with a minimum crew (2).

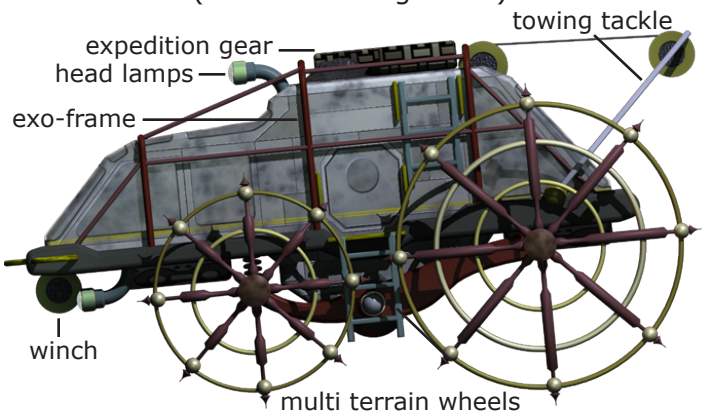
The rover's multi terrain wheels allow the vehicle to climb near-vertical surfaces of soil, wood, and soft plant tissue.

Power is generated from an onboard steam powerplant that uses alcohol as fuel. The alcohol is produced by decomposer bacteria aboard the *Cyclops* and carried in tanks on the rover.

The *Terra Rover* carries equipment for exploration, including tackle for towing and climbing, and diving suits for immersion in fluid environments.

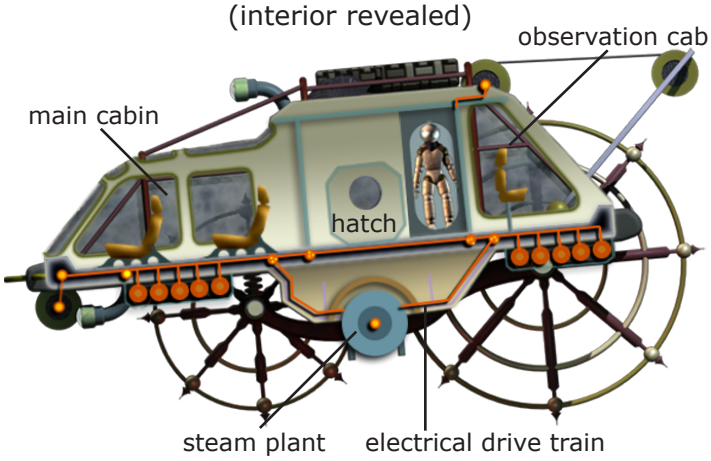
Protecting the rover are armored hull plates made of chemically resistant reinforced glass, in the unlikely event the vehicle is swallowed by some monstrous inhabitant of the terrestrial microcosm.

Left side view
(external arrangement)



Micro Vehicle Terra Rover: 350 *µm*

Left side view
(interior revealed)



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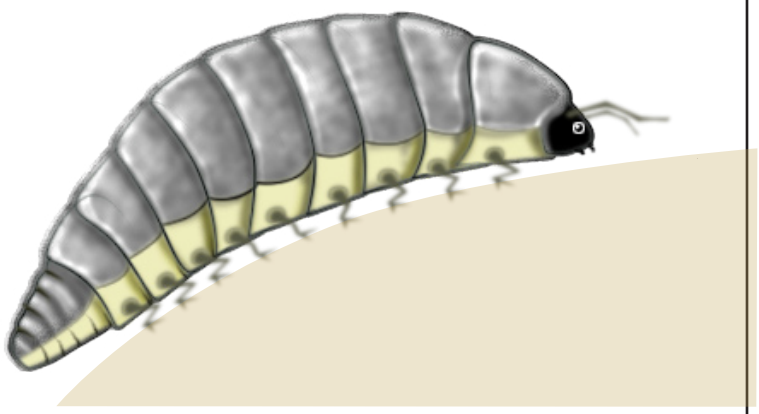


About the Organisms

Isopods: Sow bug, pill bug, and rolly poly are some of the common names given to these terrestrial crustaceans. Land inhabiting isopods live in moist microhabitats. Look for them under boards, in forest floor humus, and in compost bins. Isopods tend to feed on detritus and decomposing material of all kinds. Their respiration is carried out through "book gills" located on their lower side. Most isopod behavior is about finding and remaining in humid conditions, where the danger of drying up is limited and where decomposing food can be found. Defensive behavior consists of rolling up in a ball.

Millipedes: Millipedes are worm-like animals with many segments, each equipped with two pair of jointed legs. They are plant and detritus feeders, often found in leaf piles, rotting logs, and occassionally in bathroom shower drains. Most species have a chemical defense system and some produce cyanide compounds that are poisonous to humans if ingested. However, there is little danger, for the smell is a powerful deterrant to munching a millipede.

Centipedes: Centipedes and millipedes belong to phylum *Arthropoda*. They were probably among the first arthropods to invade the land around 400 million years ago. Unlike the slow moving millipedes, centipedes are fast and predatory. The same sharp jaws that can skewer a cricket can deliver a painful bite to soft human skin.

Other Humus Inhabitants: The forest floor is literally crawling with other forms of life. It is a nematode stronghold, sometimes with thousands of tiny round worms per spoonful.

Mites of various kinds live around the particles of decomposing plant material. Earthworms till, process and mix the soil.

Snaking through the humus and absorbing nutrients, **fungal hyphae** are everywhere. Fungi and bacteria break down the leaves and other organic fallout to basic raw materials that can be recycled into living trees and other organisms.

The Log of Captain Jonathan Adler

10:45 hours... Almost immediately we encounter a common animal of the forest floor, a bug whose outer shell is made up of overlapping plates – the sow bug. The sow bug's only form of defense is to roll itself into a ball. For this reason the sow bug is often called a pill bug or roly-poly.

The sow bug can only live where there is moisture from soil and forest decay. We found them lurking beneath rotting leaves, feeding on the decaying plant tissue, gobbling up decomposer bacteria and leaf material.

The underside of the sow bug is where we find the animal's gills, which are arranged like pages in a book. This location keeps the delicate leaf-like membranes safe and moist, necessary for extracting oxygen from the air.

11:25 hours... Working the same habitat as the sow bug, we find two other inhabitants of the forest floor hummus – centipedes and millipedes. They have similar body structure – many armored segments, but very different feeding habits.

The millipede has two pairs of legs for each of its segments. It feeds on rotting leaves and decaying forest floor matter.

The centipede is a hunter! Its long sharp jaws are ideal for capturing small insects like crickets and termites. It moves much faster than a millipede. Centipedes have one pair of legs per body segment.

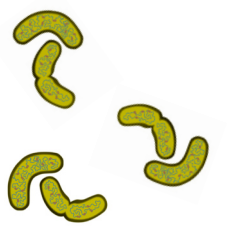
13:40 hours... A short observation-stop proves treacherous when a fast-growing bundle of living threads entangles the rover. We are unable to proceed! The threads appear to be absorbing nutrients from the rich soil, transporting them... to who knows where.

Using our clippers to free the vehicle, Tara suggests that we follow the thread system. Much to our surprise we discover that the threads converge into a single organism that rises up from the forest floor – a mushroom! The mushroom, we realize, is how a fungus reproduces. It sends spores drifting away on air currents, where they will land and start a new growth of the thread-like fungal hyphae.

Key to Organisms

Common Forest Floor Organisms

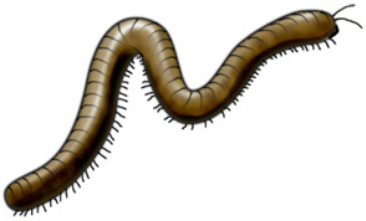
Decomposer bacteria



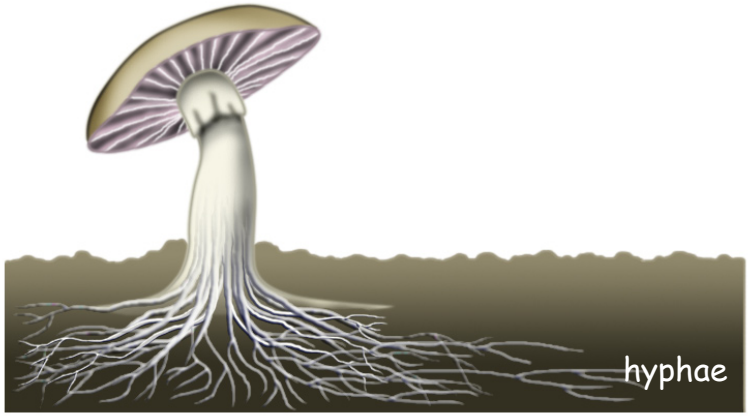
Sow bug

Centipede

Millipede



Fungi



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Accompanies Episode 10 of the 13-part video series

— *The Great Termite Kingdom* —

Written by Eric R Russell & Bruce J Russell

In this episode...

The continuing exploration of the forest floor finds Jonathan and Tara emerging from their survey of the living humus beneath a rotting log. Small perforations in the rotting wood beg further investigation, so they steer the terra rover into the maze-like catacombs of a termite gallery. In this dark labyrinth they discover that a termite's gut is home to a teeming community of protozoans that do all the work of digesting wood for the host insect.

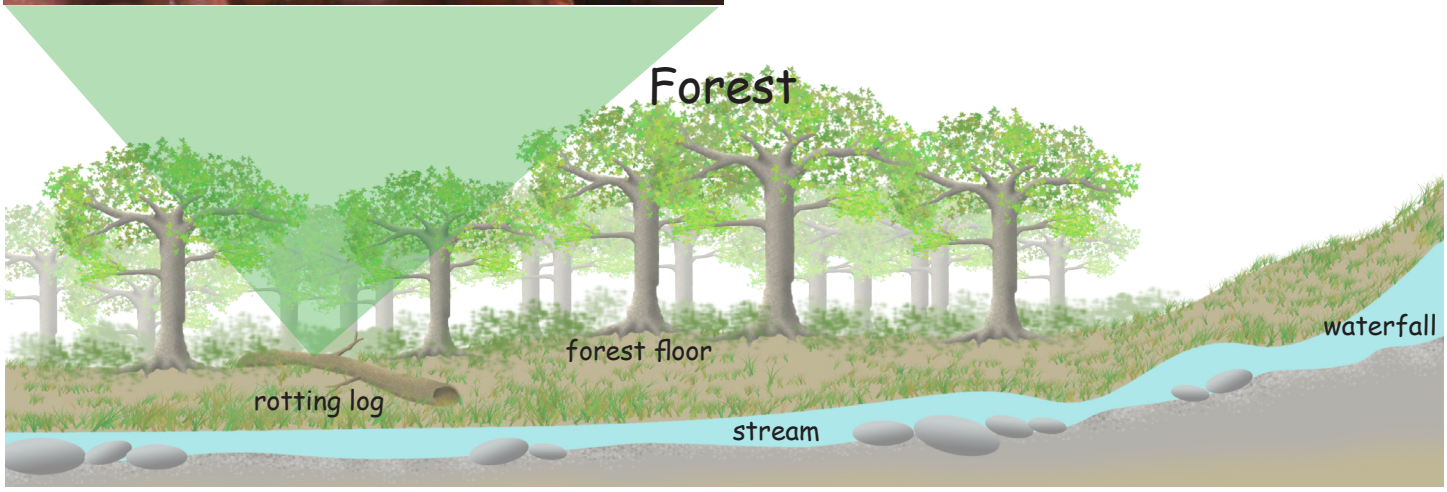
Forest Ecology: Rotting Log

The Log of Captain Jonathan Adler

Day 16: 11:30 hours... Our exploration of the forest floor continues. We have seen a great number of insects, round worms, mites, and assorted other scavengers, predators, and harvesters. All contribute to the breakdown of dead forest material, such as wood and leaves. The soil becomes enriched, and the trees and other living plants benefit. Decomposing and processing the dead cells of a leaf are one thing, but we wonder how does the forest floor ecosystem deal with something as enormous and solid as a fallen tree?

12:10 hours... It isn't long before we discover the answer! Climbing up from the humus we find ourselves beside a massive object – a fallen log! The wood is covered with holes, and keen-eyed Tara catches a glimpse of something moving inside.

Perhaps we have uncovered the secret of how a fallen log returns to the soil. With a triumphant shout, Tara declares: "Follow that bug!"



Terra Rover

Terrestrial auxilary to MS Cyclops

Vehicle Dimensions

LENGTH	.35 mm
BEAM	.22 mm

Vehicle Mission

Maximum speed	3 cm per minute
Mission duration	10 days

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The rover's multi terrain wheels allow the vehicle to climb near-vertical surfaces of soil, wood, and soft plant tissue.

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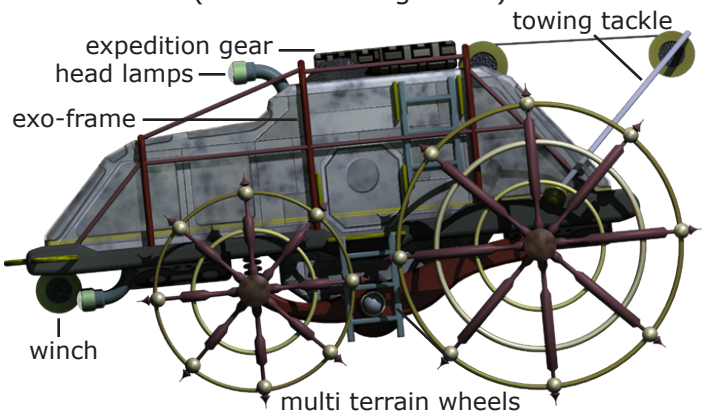
The *Terra Rover* carries equipment for exploration, including tackle for towing and climbing, and diving suits for immersion in fluid environments.

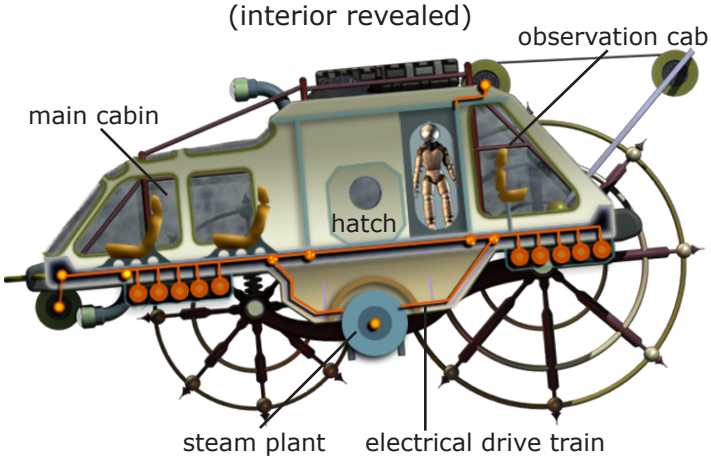
Protecting the rover are armored hull plates made of chemically resistant reinforced glass, in the unlikely event the vehicle is swallowed by some monstrous inhabitant of the terrestrial microcosm.

Left side view
(external arrangement)



Micro Vehicle Terra Rover: 350 *µm*

Left side view
(interior revealed)



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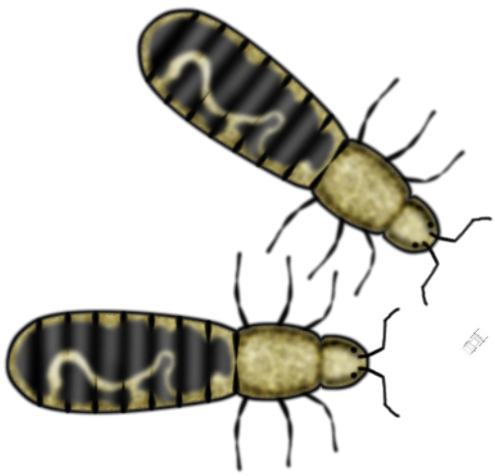
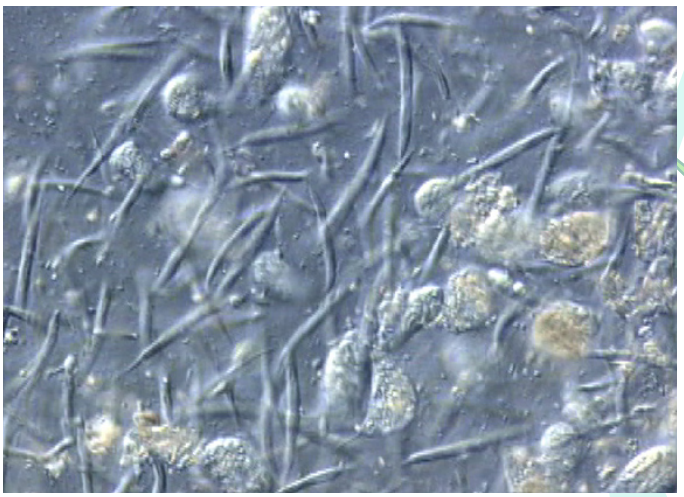


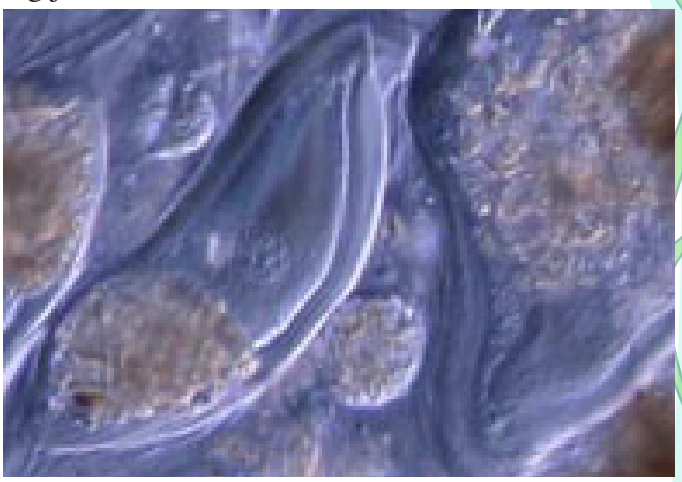
About the Organisms

Termites: In temperate zone forests **termites** invade fallen trees soon after **bacteria** and **fungi** have begun to soften the dead wood. Fallen logs are a special habitat where one can examine an interesting relationship between termites and the microscopic partners that live in the termite digestive system.

The large termites seen in this program do not attack houses unless they are made of old, partially decayed pine logs. They break down wood with the help of bacteria and protozoans that live in special stomachs located near the end of the termite's intestine.



If a termite is "cleansed" of its **symbiotic helpers** using antibiotics, it will continue to eat wood. Without helpers, the termite will soon die of an internal log jam.



The relationship between termite and its wood digesting microbes is a classic example of **mutualistic symbiosis** — each species requires the other in order to survive.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

12:30 hours... We have entered the fallen log through one of the insect holes. What will we find in this lightless world?

We fire up the head lamps. Termites by the hundreds appear before us, populating a complex gallery of tunnels and chambers that riddle the interior of the log.

Two kinds of termites are visible – the workers, and the larger soldiers with long sharp mandibles. We assume that somewhere in this vast colony is a termite queen, responsible for laying eggs.

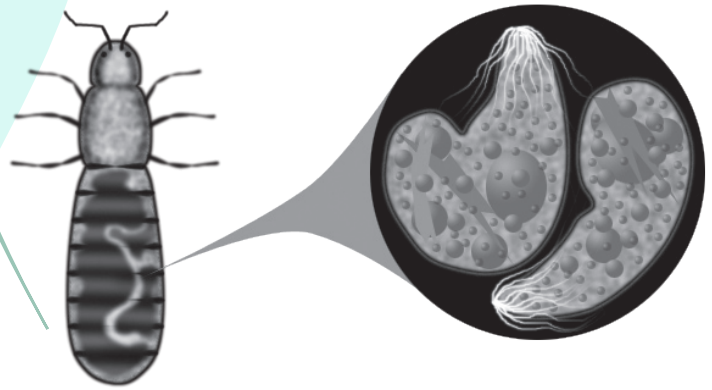
The workers are busy little insects, relentlessly munching away on the log. With magnification we can see the wood chips inside a termite's stomach – and swarming around those wood chips... something else.

Before I can stop her, Tara grabs a diving suit and sets out to discover what is living inside the termite's gut!

The termite's stomach and intestine, to our surprise, are full of various kinds of single-celled microorganisms!

The termite does not digest the wood after all. That is the job of its digestive helpers! The termite chews up bits of wood, swallows – but the process of digestion cannot begin without help from the hungry inhabitants of it's innards! The relationship between the termite and its guests is called symbiosis.

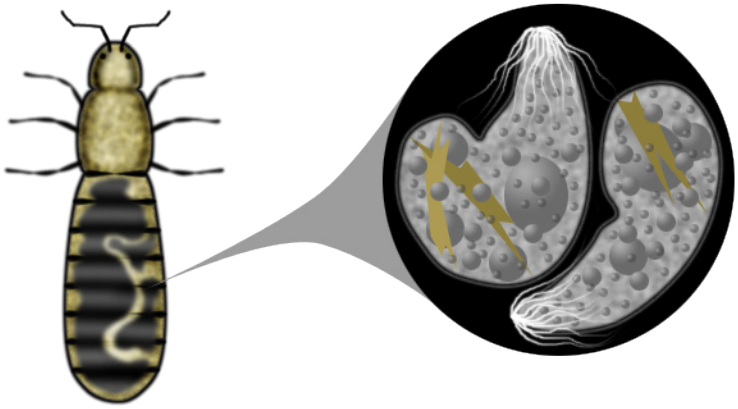
Without this symbiotic relationship, the termite would be unable to digest a single chip of wood and would starve.



Key to Organism

The Woodland Termite and Internal Helpers

The termite's digestive system is home to a variety of microbes that aid in breaking down wood chips. In this way, a colony of termites processes the dead wood of a rotting log, returning its nutrients back to the forest to the benefit of other organisms.



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Accompanies Episode 11 of the 13-part video series

— *Plant Prospectors* —

Written by Eric R Russell & Bruce J Russell

In this episode...

Taking to the air in their flyer, the microsopic explorers discover that lawns and flower gardens are home to a variety of insect pollinators and voracious predators. Honeybees, butterflies, ladybird beetles, aphids and soldier beetles illustrate the role insects play in the ongoing health of the backyard ecosystem. And when a larger animal dies, such as a mouse or squirrel, scavanger insects swoop in to harvest the carcass. This process accelerates decomposition, releasing nutrients back into the ecosystem.

Backyard Ecology: Garden

The Log of Captain Jonathan Adler

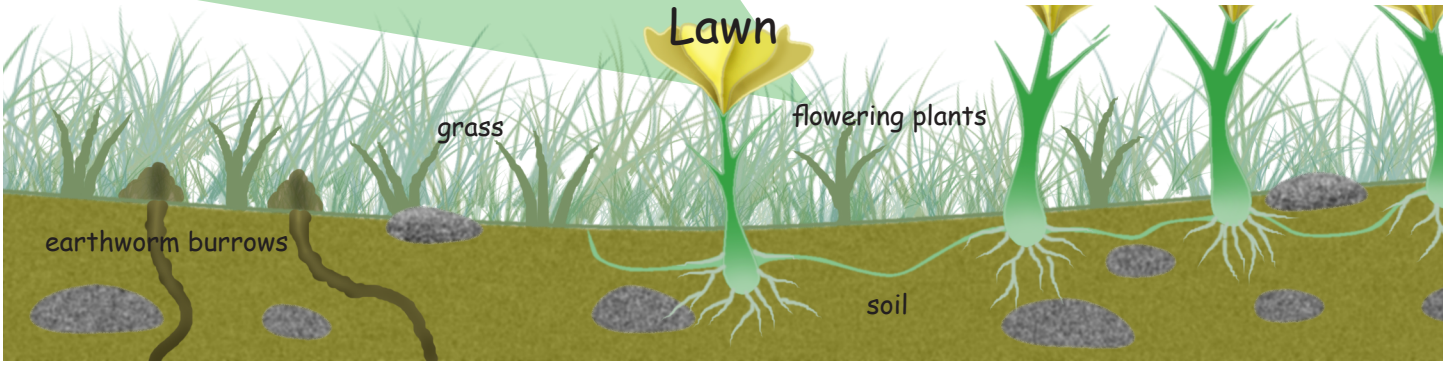
Day 17: 07:30 hours... To speed up our journey overland, Tara and I have assembled her flyer. We have parked the rover safely in the grass at the edge of an expansive lawn and garden. We suspect that this area will be excellent for observing how insects and plants work together.

Our first encounter is with a beautiful large 4-winged insect. The **butterfly** uses a long tube-like snout to reach deep into a flower's inner parts, extracting irresistable sweet nectar. We wonder why a plant would produce sweet nectar?

Moments later we spy a faster moving flower-feeder... a furry fellow that picks up yellowish pollen grains as it burrows into the flower for nectar – a **honeybee**. Why would a plant want to attract these insects?

Pollen is the answer! By luring them with sweet nectar, the flower uses both the honeybee and the butterfly for the same purpose. Flower pollen sticks to the insects. When they fly away to another flower, the pollen is transferred, and seeds begin developing. This is the process of pollination.

The flowers that grow into fruits, nuts, and berries, are all pollinated by insects.



Flyer

Aerial auxilary to MS Cyclops

Vehicle Dimensions

LENGTH	.65 mm
WINGSPAN	.75 mm

Vehicle Mission

Maximum speed	1 meter per minute
Mission duration	2 days

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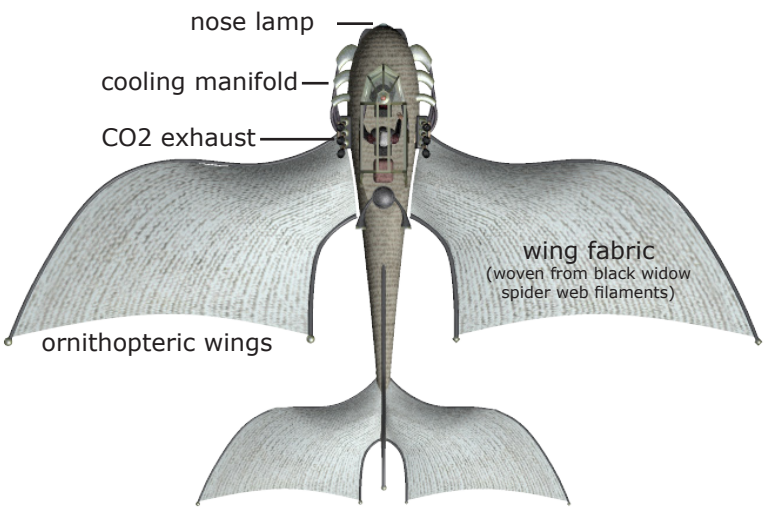
The flexible fabric of the Flyer's wings are made from a woven mesh of black widow spider web filaments. The fuselage is constructed from a basket-like weave of cellulose plant fibers.

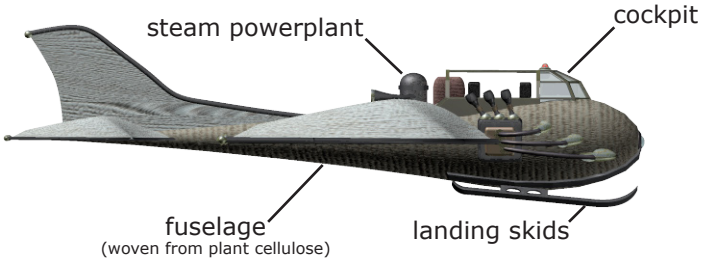
Power is generated from an onboard steam powerplant that uses alcohol as fuel. The alcohol is produced by decomposer bacteria and is carried in small tanks aboard the flyer.

Requiring a single pilot, the Flyer can carry a second microscopic passenger for aerial explorations and reconnaisance.

Top view



Right side view



Oblique view

Contents of this guide...

About the Organisms

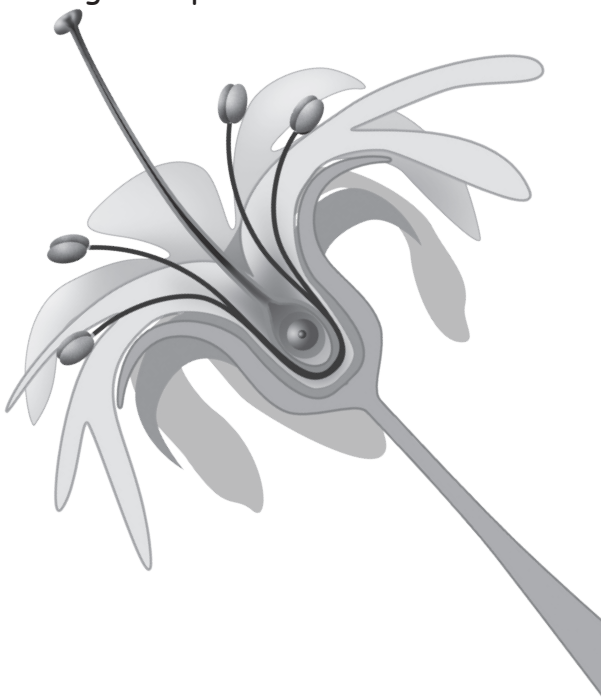
A yard is filled with biological surprises. There are often more kinds of living things to be found in gardens and backyards than you might expect. Some of the most interesting are the flowering plants and the insect pollinators, pests, and predators that live with them.

Flowering Plants

Flowers are a plant's way of announcing to a passing insect that a treat awaits if it will just land and start sniffing around. To get at that sweet nectar the insect must rub against the anthers, picking up pollen grains along the way. When the insect goes in for another flower's nectar the pollen grains rub off onto the sticky stigma.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler



12:30 hours... Plants and insects have a perfect symbiotic relationship! The two species help each other.

We believe that many insects have life cycles that coincide to the growing season of flowering plants. Spring!

The adult forms of insects such as the butterfly are busy during the same season that plants are producing flowers. And since flowers are a flowering plant's way of making seeds, it can be said that a flowering plant essentially tricks insects into helping it make more plants.

Honeybees are particularly good pollinators. They travel far from their hives in search of the sweet nectar from which they make honey. This behavior sends them visiting and pollinating hundreds of flowers a day. This is why a honeybee is a gardener and fruit grower's best friend.

If the honeybee population were to suffer from pesticides or insect disease, it could hurt not only the busy bees themselves, but also the plants and people who rely on them.

About the Organisms

Predators in the Garden

Young, fast growing garden plant stems have soft tissues and are often targeted by insects as a food source. The new growth of a garden variety rose bush is a good place to find a thriving population of aphids.

Aphids are very efficient reproducers. Large females give birth to many babies. The young **nymphs** immediately stick their beaks into the host plant and begin sucking its juices. The plant is soon swarming with destructive little juice suckers. The aphids rob the plant of nutrients and create wounds that allow bacteria and viruses to enter. But these sap sucking insects have enemies that prevent them from killing the plant.

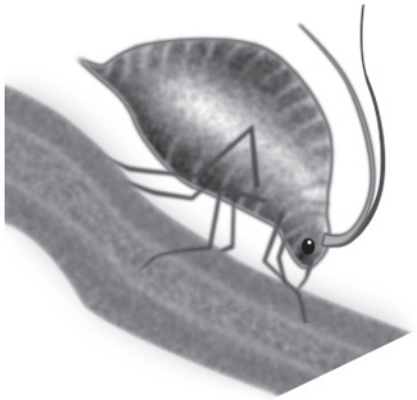
Aphids are the food of choice for predator insects, **soldier beetles** and **lady bird** beetles (ladybugs). The soldier beetle has a behavior that keeps it clean and tidy: using its front set of legs to keep its mouth clear of aphid parts and sticky sap.

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

14:30 hours... We soon discover that the beautiful world of the flower garden is also home to destructive pests!

Small insects called aphids make a home on plant stems. There are thousands of them! They use their beaks to suck out the sap and fluids, which is certainly not beneficial to the plant. We wonder what stops these pesky little juice-suckers from killing the plant?



With the sound of crunching and munching we are alerted that company is here! The pesky aphids are now the snack of choice. Two kinds of predator insects have arrived to feast on the pests, and they are hungry! The predators gobble the plant parasites as fast as they can munch.

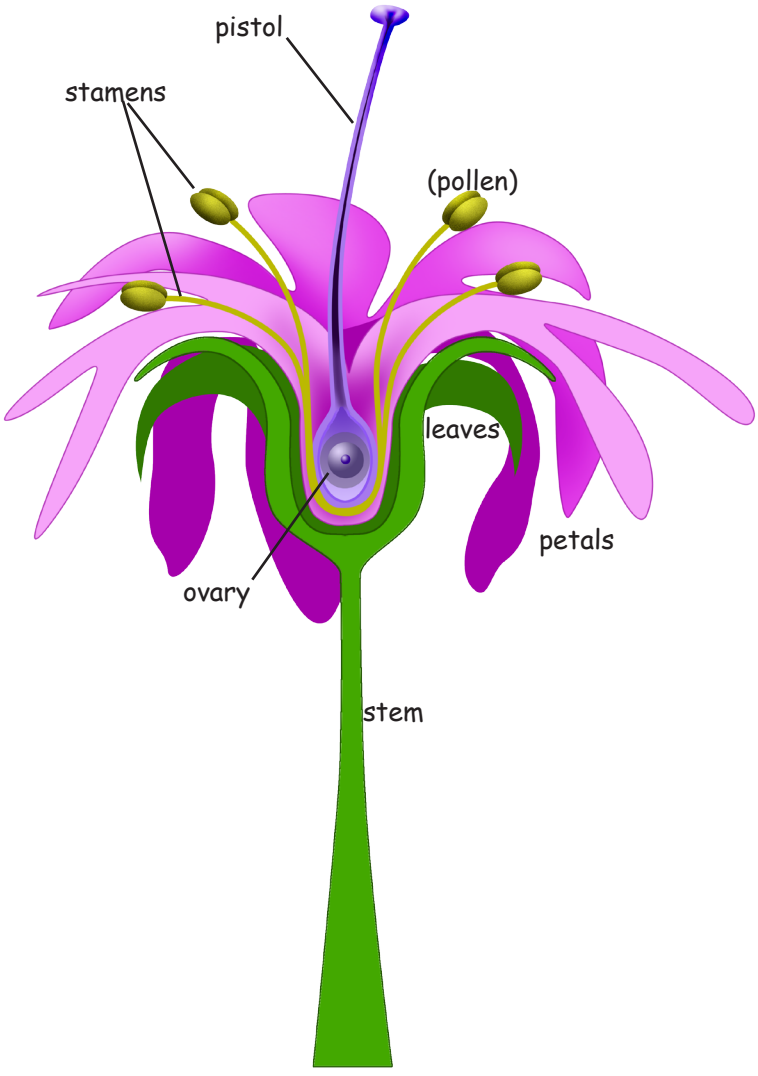
The larger of the predators, the soldier beetle, eats so quickly that sticky sap and chewed-up aphids collect on its mouth parts. But this is the neatest insect we have ever seen! It periodically wipes its mouth clean with its front set of legs.

As we take to the air and make our way back to the rover, we look down to see scavanger insects picking at the carcass of a dead rodent – the beginning of another food chain. Just like the microworld of the pond, we now see that the backyard flower garden is a system of producers and consumers, of predators, prey and scavangers. Every organism plays a role in keeping the system alive and healthy.

Key to Organisms

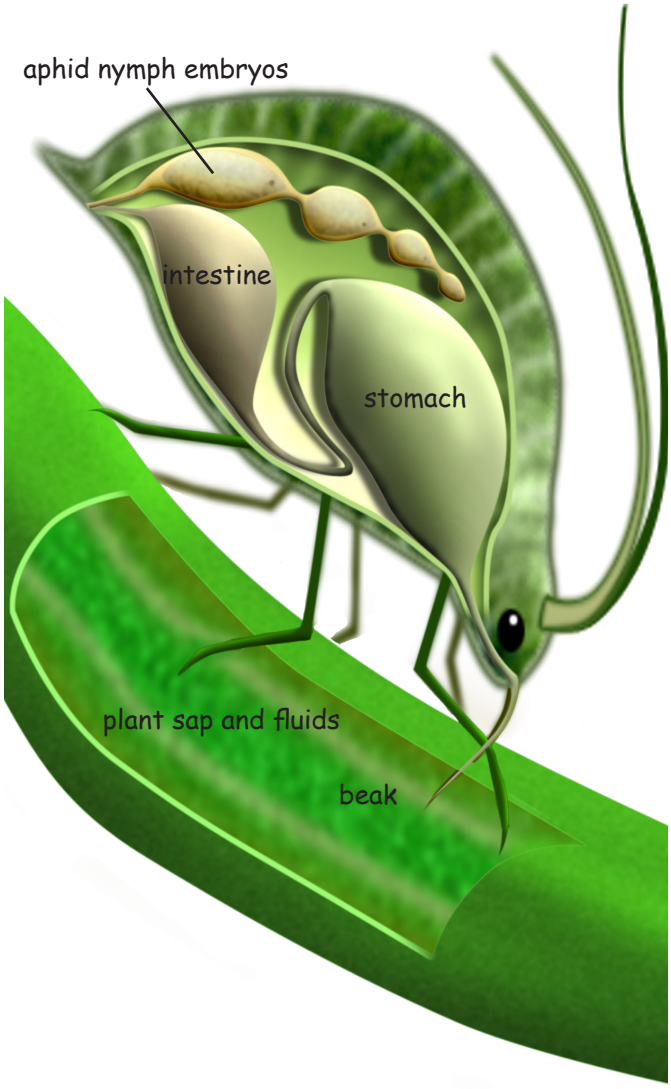
Flower

Flowers are a plant's way of making seeds. Some flowers are pollinated by wind and air, others by insects. When an insect dives into the middle of the flower seeking sweet-tasting nectar, pollen grains from the stamens stick to its body. When the insect moves on, the pollen is transferred to the pistol of a new flower. It travels down the pistol to the ovary where it develops into seeds.



Aphid

A female aphid can produce many baby aphids (nymphs) every day. They are clones of the mother aphid. New plant growth in the flower garden can be quickly overcome by a carpet of tiny aphid nymphs, which begin making their own babies. Luckily plant-friendly predators such as ladybugs find aphids to be delicious.



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Accompanies Episode 12 of the 13-part video series

—*Lair of the Earthworm*—

Written by Eric R Russell & Bruce J Russell

In this episode...

When a subterranean monster swallows their rover the crew must pursue the beast into its volcano-like mound. Here, they unearth the culprit – an **earthworm**. Within the worm's sunless burrow, they unravel the basic plan of **annelid anatomy** and learn it is not radically different from many more advanced land dwelling animals. From these observations, the explorers develop theories about the role earthworms play in maintaining **terrestrial ecosystems**.

Backyard Ecology: Lawn Soil

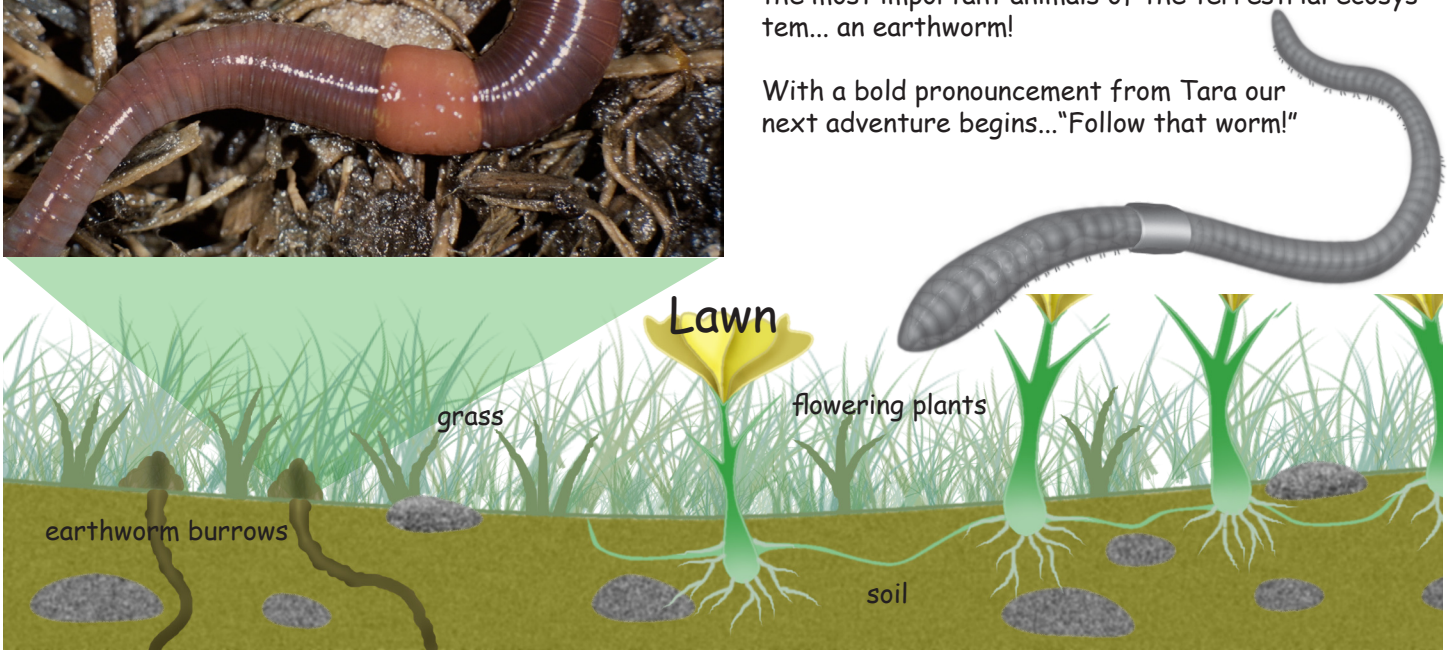
The Log of Captain Jonathan Adler

Day 18: 09:00 hours... It is with some embarrasment that I must report that we have misplaced our Terra Rover!

From the flyer we search the area where we believe we parked the rover – but, unlikely as this sounds, the terrain seems to have changed while we were exploring the garden ecosystem. Nothing is familiar! And most mysteriously, there are fresh mounds of new earth throughout the lawn.

To my relief Tara's keen eyes find our missing vehicle. Eager to reclaim it, we land on one of the new earthen mounds nearby. We are about to hike over to the rover when the soil beneath it suddenly pushes upward! What is happening? We stare helplessly as the earth opens under the rover and something swallows it whole! It is an animal – more specifically it is one of the most important animals of the terrestrial ecosystem... an earthworm!

With a bold pronouncement from Tara our next adventure begins..."Follow that worm!"



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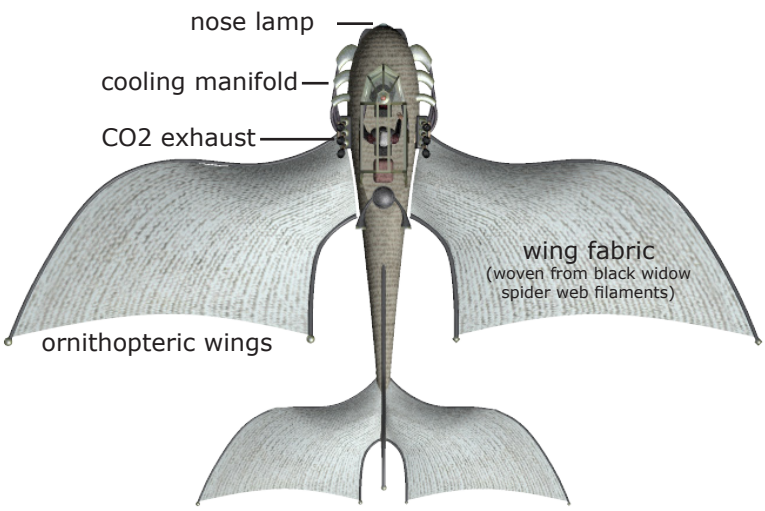
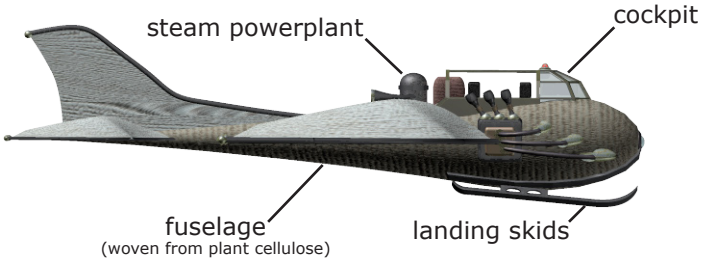
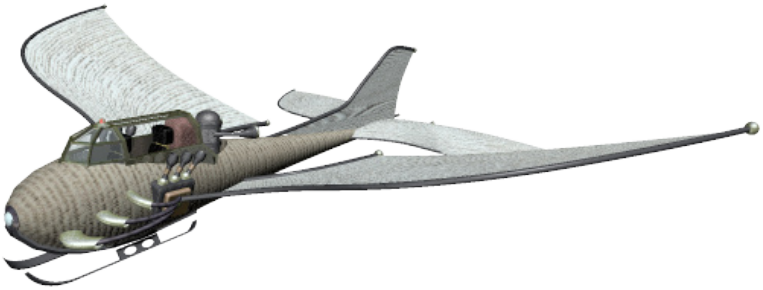


Right side view



Oblique view



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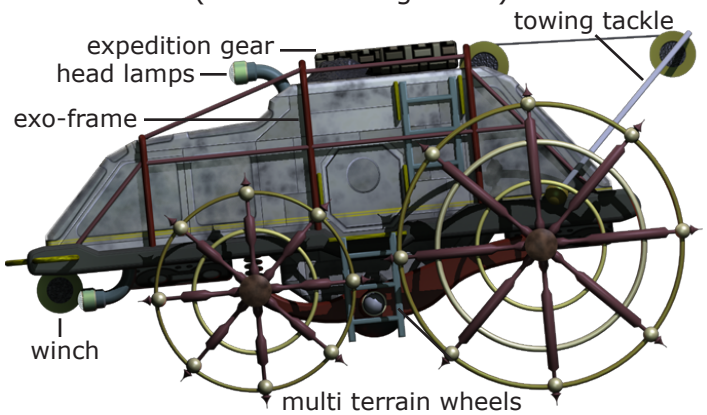
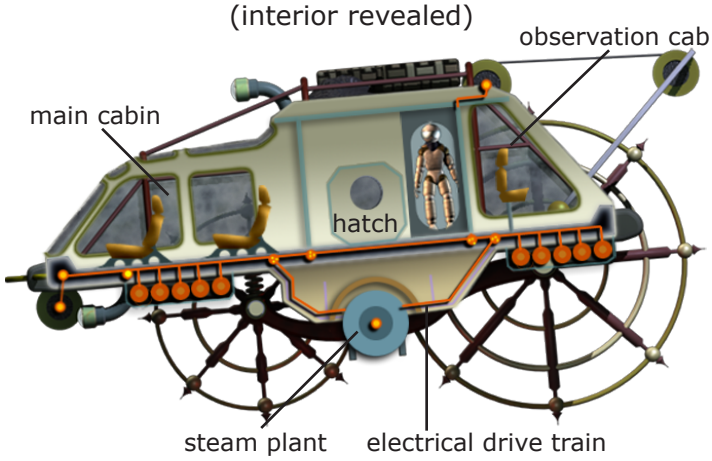
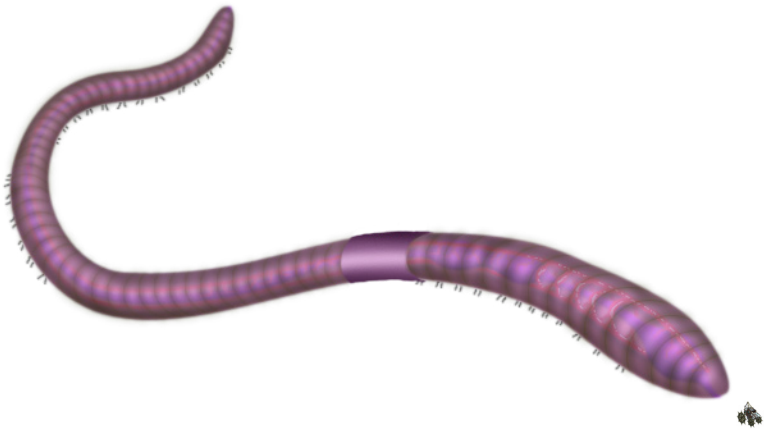


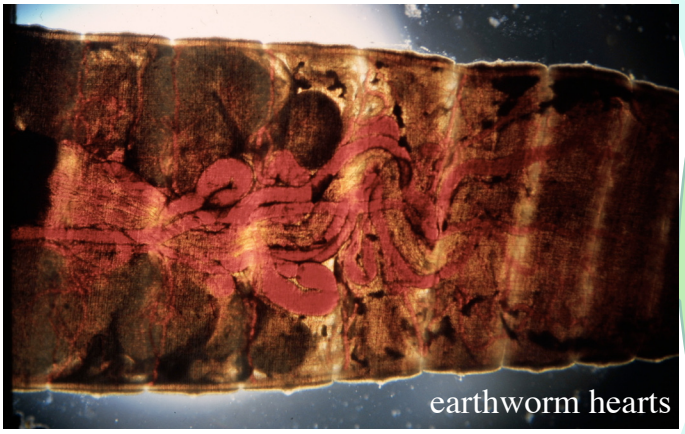
Left side view
(interior revealed)





About the Organisms

Earthworms are welcome inhabitants of yards, gardens, and agricultural fields. They cultivate and process soil, converting organic substances into waste materials to be used by plants.


earthworm hearts

The earthworm's anatomy clearly shows how they enrichen the earth with nutrients. Soil (containing insect eggs and decaying plant parts) is swallowed. Soil is mixed and ground up in an organ called the **gizzard**, then passed down the long **intestine** where **digestion** and absorption take place. Finally, it is eliminated above ground in the form of worm castings. **Worm casings** are extremely rich components of healthy soil and are very good for plants.

The earthworm has a complex **circulatory system**. Surrounding the **esophagus** are **five hearts**. They are the pumps that carry nutrients to all parts of the earthworm's body. Blood flowing through **capillary beds** in the worm's moist skin pick up oxygen and release carbon dioxide. Earthworms are **hermaphroditic** – each is both male and female. **Eggs** are deposited in a cocoon made of secretions produced by the **clitellum** – a ring-like structure obvious on earthworms.


earthworm egg

EXPLORATION GUIDE & JOURNAL

The Log of Captain Jonathan Adler

11:30 hours... Equipped with climbing tackle and lamps, Tara and I descend into the earthworm burrow. A few millimeters below the surface we find the soil to be cool and moist, conditions we believe are ideal for healthy earthworms.

The monster is resting for the moment. It does not breath with lungs – its skin can evidently absorb oxygen from air, which explains why it must remain moist.

Tara suggests that shining one of our lamps through the worm might illuminate the beast to reveal more about its internal organs – and help us locate our rover.

Tara's lamp does the trick! The worm's internal organs are now easily visible. Its red-blood filled circulatory system travels down one side of its body and back again up the otherside. What pumps all of this blood throughout the worm? Tara's light reveals, not one... but five steadily beating hearts!

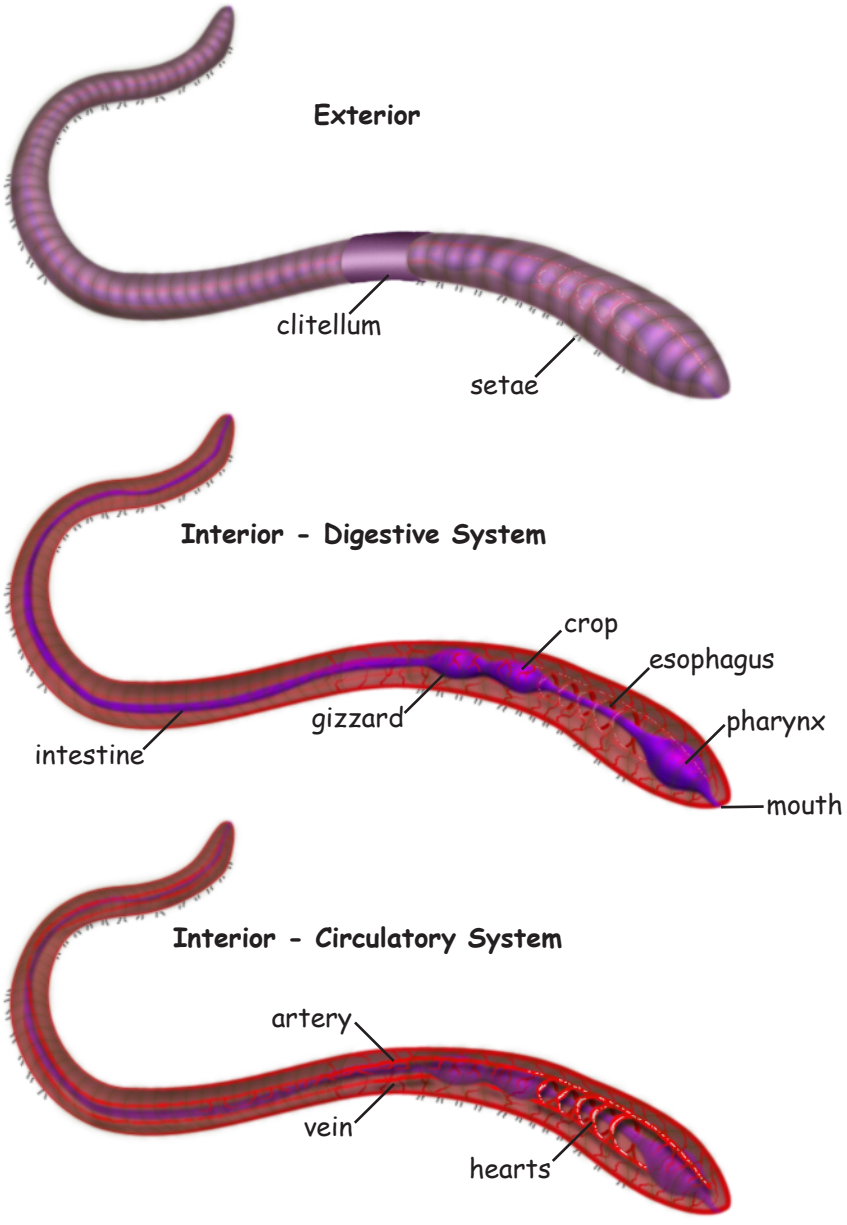
Running down the center of the earthworm is its digestive tract, where soil is mixed with organic debris such as fallen leaves and insect eggs... and our Terra Rover. Soil is ground by organs into a muddy mixture. The intestine is where nutrients are absorbed before the enriched soil comes out the tail end. And that, we now see, is what makes those mysterious mounds!

Luckily, it isn't long before the earthworm's efficient digestive system delivers our rover back to the surface, almost where we left it! We bid farewell to the backyard ecosystem and make our way back to the Cyclops.

Key to Organisms

Earthworm

Earthworms are the primary workers for returning nutrients from leaves and organic material back into the soil for use by plants. They make burrows, and use hair-like setae for anchoring and moving through soft humus. Each worm is both female and male. An earthworm's moist skin transfers oxygen to blood capillaries in the circulatory system, and expels carbon dioxide. Like humans, the earthworm's blood is red, based on hemoglobin. But instead of just one, a worm has five hearts that keep blood constantly circulating, moving nutrients and oxygen to all parts of its body.



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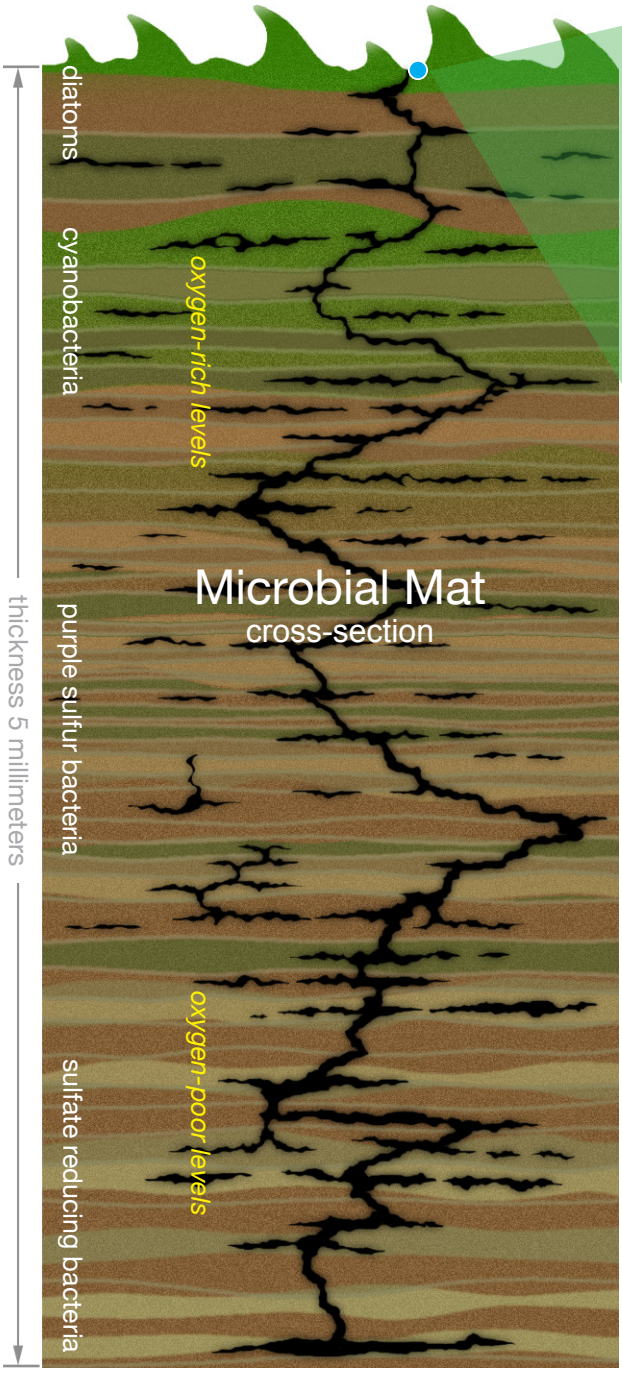
Accompanies Episode 13 of the 13-part video series

— *Stromatolite Explorer* —

Written by Eric R Russell



Marine Ecology: Microbial Mat

The Log of Captain Alda Adler

Day 1: 09:00 hours... My first mission! My first log entry... Grandpa Jon would know exactly what to say. He would know the perfect words... something inspiring and courageous. But, my crew and I are diving into a microcosm that he didn't even dream of exploring – **the extreme environment of a shallow salty sea**.

Our mission is to survey and discover the chemical conditions to a depth of 5 millimeters – of **a living microbial mat.**

We want to learn as much as possible about this extreme Earth micro habitat. **Exobiologists** believe that this is the kind of harsh environment where life on other planets might be found. What we find here is the kind of life that human explorers to other planets will most likely encounter.

The mat's spiky surface is caused by filaments of **oxygen-producing bacteria** pushing upward from below, creating a mountainous landscape. Our vessel, *Stromatolite Explorer*, will enter a microbial mat through a fissure on the surface. We intend to follow gaps and pockets in the living mat until we reach our destination.

Stromatolite Explorer

Extreme Micro Enviro Reconnaisance

Vehicle Dimensions

LENGTH	.1 mm
BEAM	.08 mm

Vehicle Mission

Maximum speed	1.5 mm per minute
Mission duration	2 days

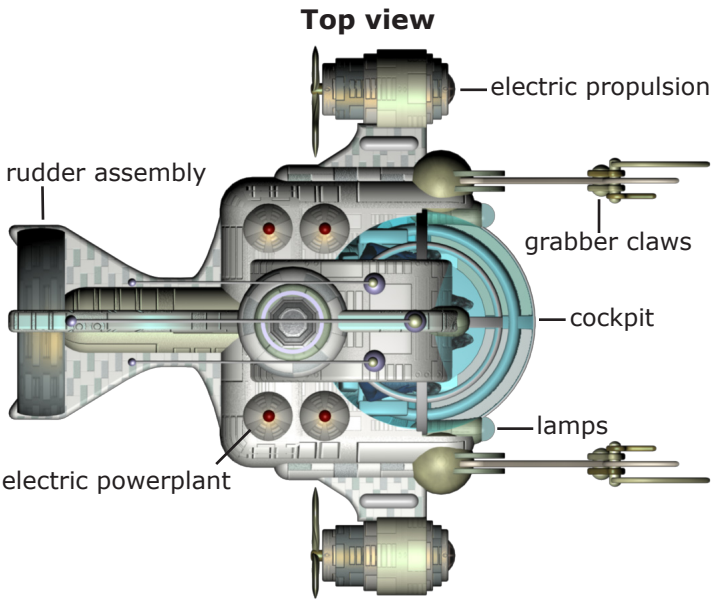
The *Stromatolite Explorer* is a sub-microscopic exploration vehicle designed to withstand the extreme conditions of Earth's harshest environments.

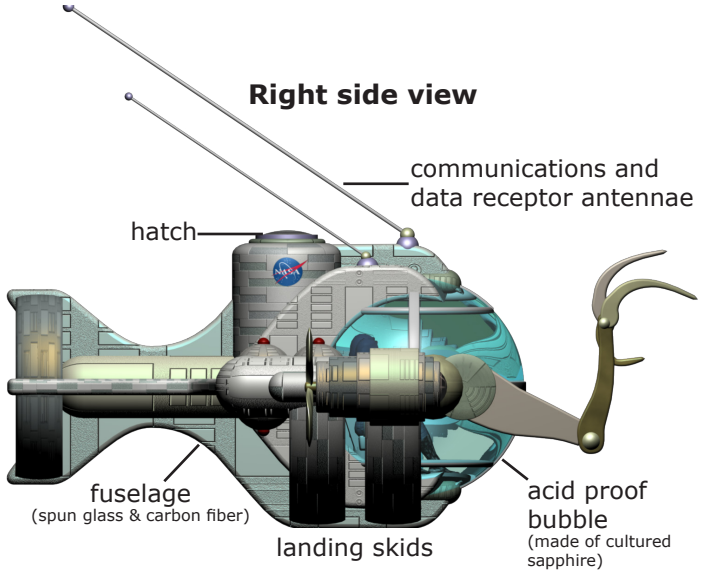
The *Explorer's* mission is to carry an investigative team of exobiologists to record environmental data in primitive-earth conditions – conditions similar to those that might be found on other planets.

Such challenging harsh environments are the ideal place to search for simple, primitive life – the kind thought to inhabit Earth approximately 3.5 billion years ago.

Launched in 2035, the vehicle is built from spun glass plating with carbon fiber reinforced exoskeleton. Power is an electrical cell, with photo-sensitive recharge. Twin outrigger motors allow maximum maneuverability. Articulated grabber claws allow handling of samples for close examination.

Requiring a single pilot, the *Stromatolite Explorer* can carry a second microscopic mission specialist for the full mission duration.





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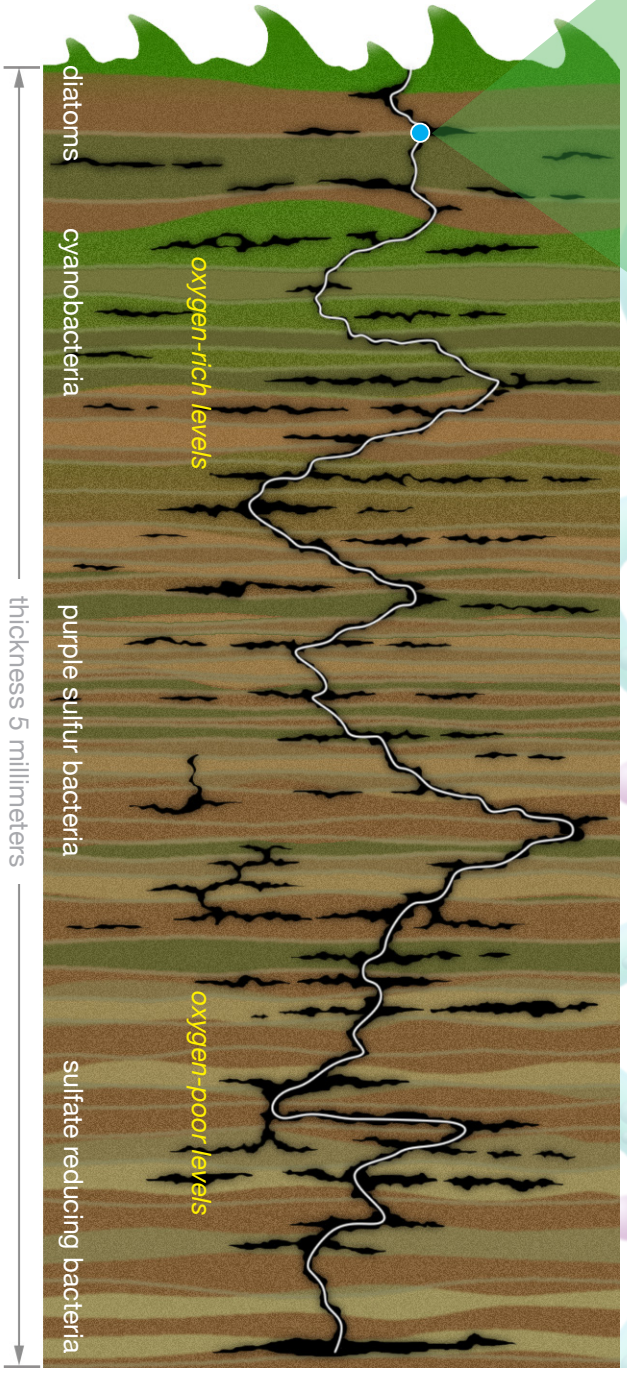
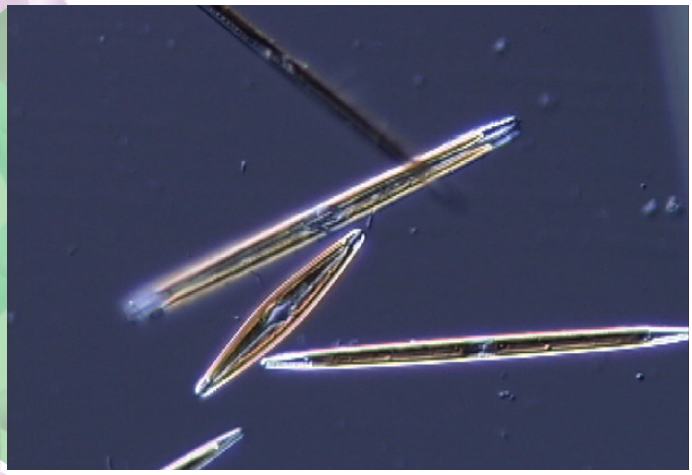
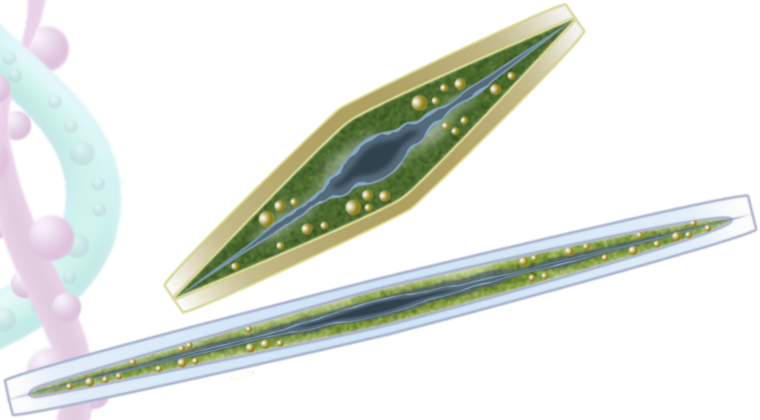


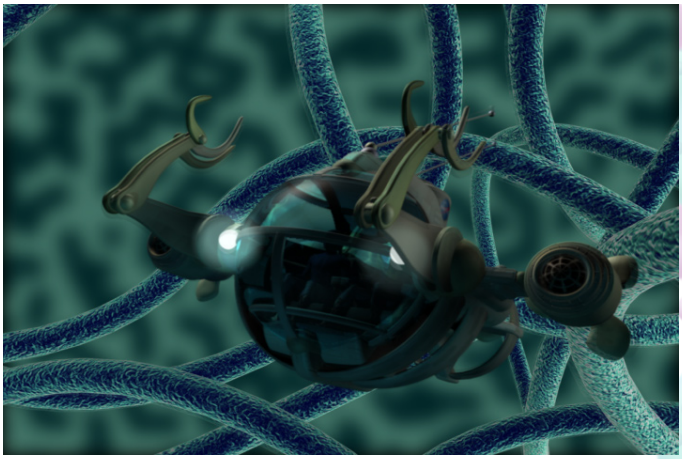


The Log of Captain Alda Adler

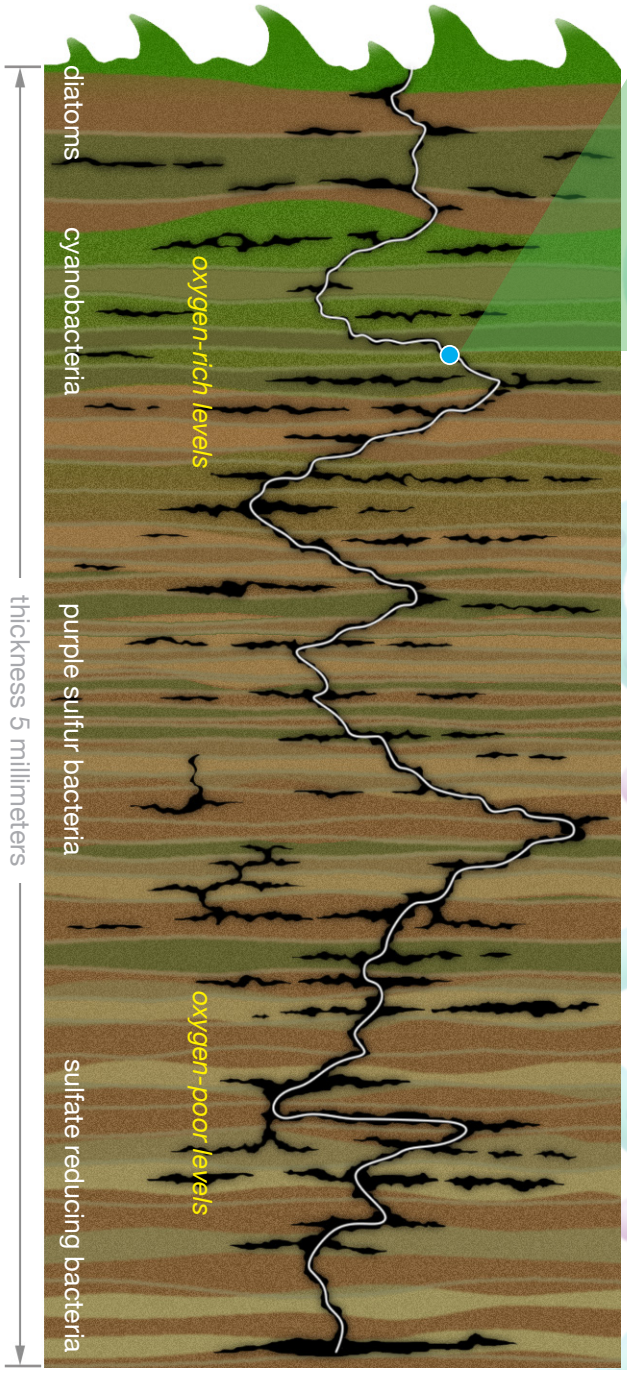
Day 1: 10:20 hours... Diatoms! *Stromatolite Explorer*, in the upper half millimeter of the mat, enters swarms of free-drifting diatoms. These **single-celled algae** are encased in glass, and made buoyant by **oil droplets** inside their silica houses.

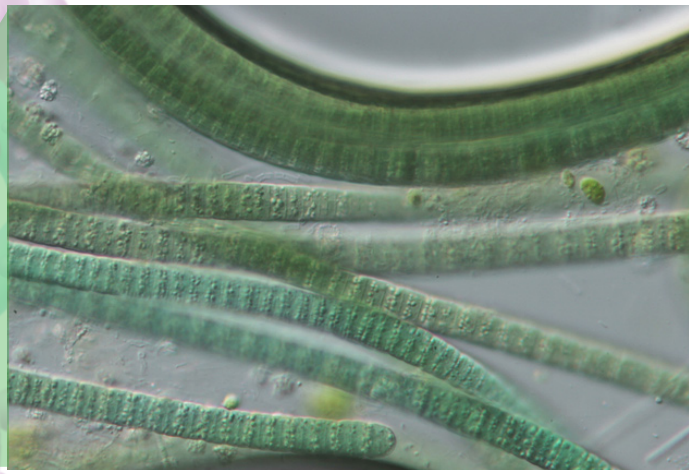


Diatoms are active **photosynthesizers**, receiving plenty of sunlight for making this upper most region of the mat very oxygen-rich! Because there is so much oxygen available, this level is home to micro animals such as nematodes. We wonder if we will find these light-dependent organisms deeper in the mat as we descend.



Depth: 1.2 millimeters



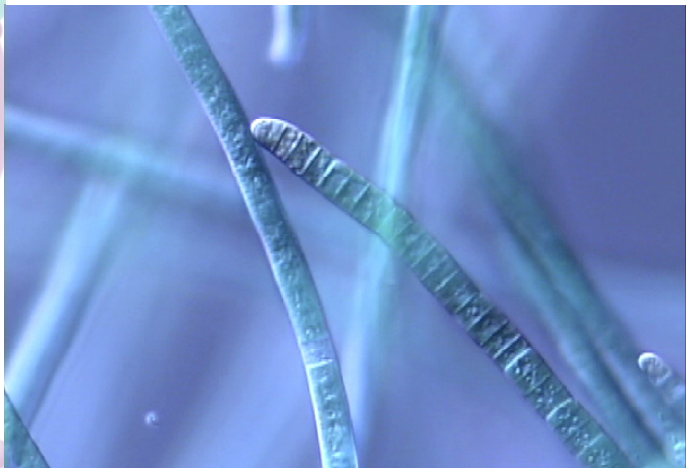


The Log of Captain Alda Adler

Day 1: 11:00 hours... At the 1-millimeter depth we enter the world of ***cyanobacteria***. The strands are interconnected cells, but none contain a nucleus. They form long chains that bend and stretch.

Cyanobacteria, also called **blue-green algae**, produces oxygen when sunlight is present. Oxygen bubbles many times the size of our ship are visible forming within the dense strands.

We deploy the *Explorer's* grabber claws to assist with navigating through this increasingly dense living maze. The path grows darker as we descend, and oxygen levels begin to dip slightly as less and less sunlight penetrates the mat.



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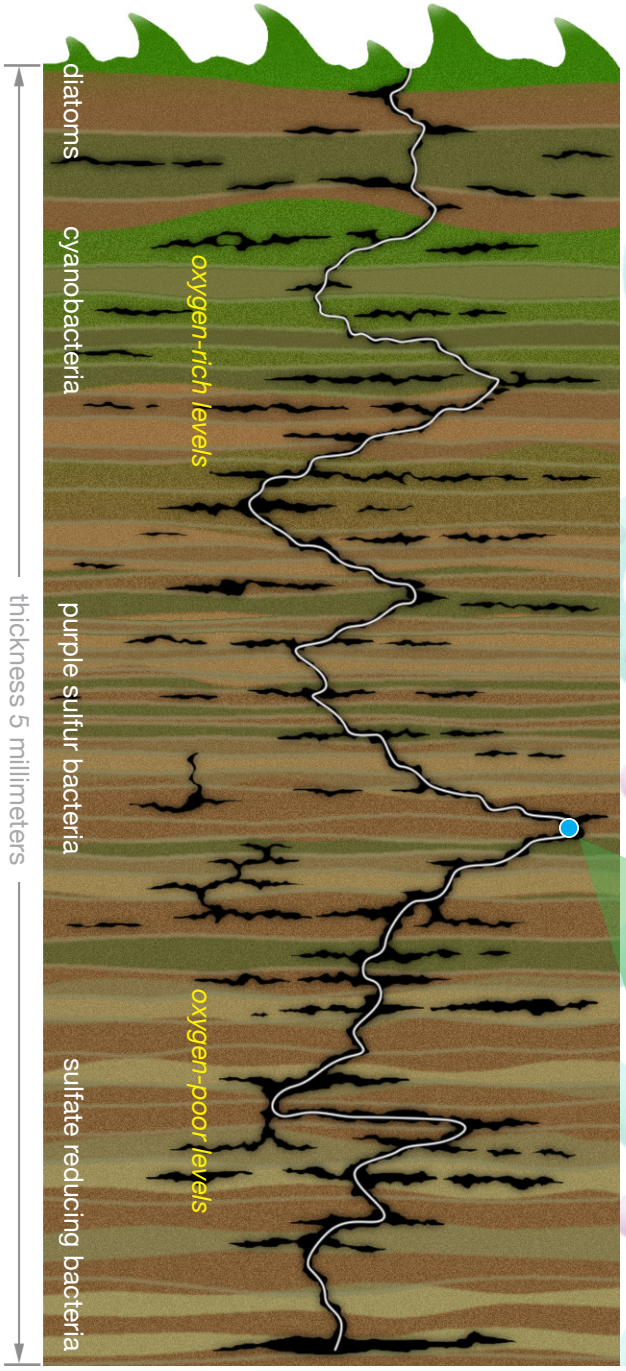
DEPTH	O2	H2S	pH
0.5 mm	600	0	9.2
1 mm	1000	0	8.75
2 mm	0	20	7.5
3 mm	0	100	7
4 mm	0	140	6.8
5 mm	0	150	6.6

Diatoms
Cyanobacteria
Purple Sulfur Bacteria
Sulfate Reducing Bacteria

Depth: 3 millimeters

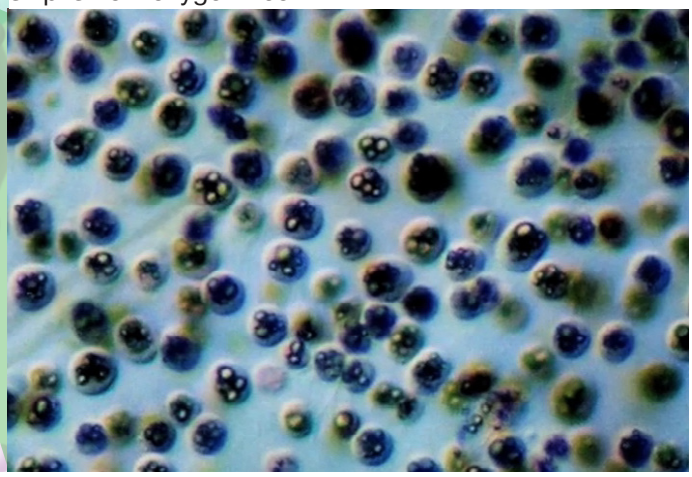


The Log of Captain Alda Adler

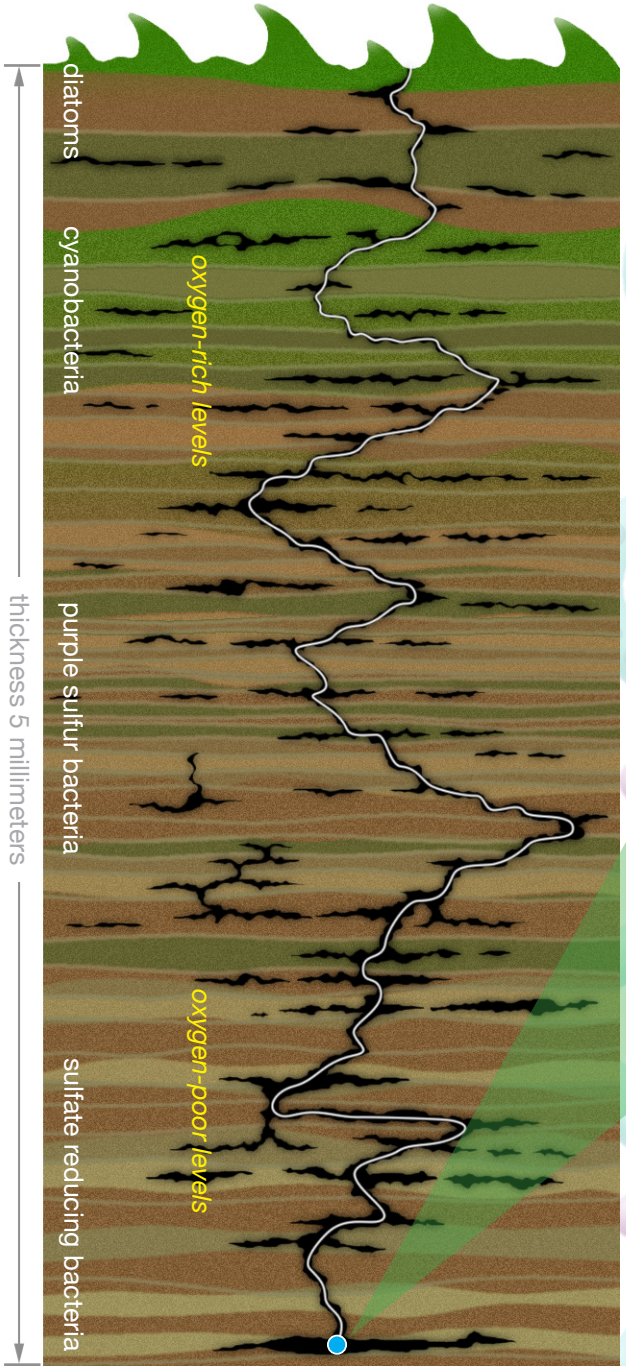
Day 1: 11:40 hours... Three millimeters into the mat now. Sunlight is dimmer here, and the nature of the mat population has changed. We have entered the realm of **purple sulfer bacteria**.

These small spherical cells use the existing dim light to power themselves, but they do it in a different way. This is not the photosynthesis of green organisms like cyanobacteria and algae. Purple sulfur bacteria use **hydrogen sulfide** instead of water to capture photons and make energy molecules.

These strange simple cells do not produce oxygen, and our instruments confirm that the environment outside the ship is now oxygen free!



Depth: 5 millimeters



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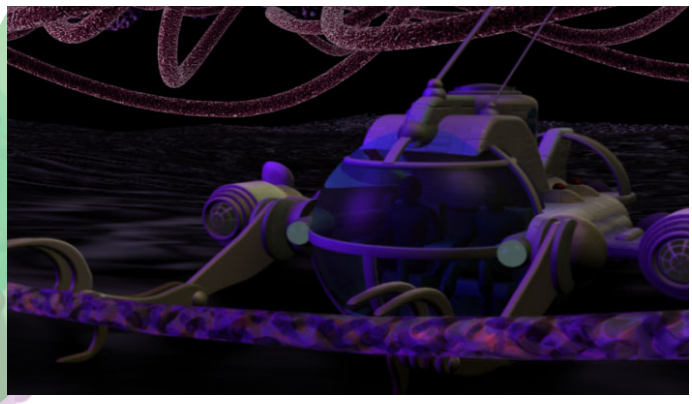
The Log of Captain Alda Adler

Day 1: 18:00 hours... We arrived at the bottom of the mat 8 hours ago. This region is utterly dark. No sunlight penetrates this deeply into the mat.

For 8 hours we have been collecting data at the darkest level of the microbial mat community. To our amazement there is still life, but very different than the kind of life found near the sunlit surface. Strands of **sulfate reducing bacteria** thrive down here. These strands appear to migrate up and down through the layers of the mat as night falls.

We hear an alarm, and are alerted by our computer that we are out of power! To make matters worse we cannot recharge our batteries, because there is not enough sunlight. We are stranded down here at the bottom of a microbial mat! Unless...

Our onboard clock tells us that up in the surface world the sun has set. Maybe this is our chance to escape! If we time it right, perhaps we can grab onto one of those migrating strands of sulfate reducing bacteria and catch a free ride back to the surface!



The plan works! During our return trip we gather more data and learn just how active the mat is at night!

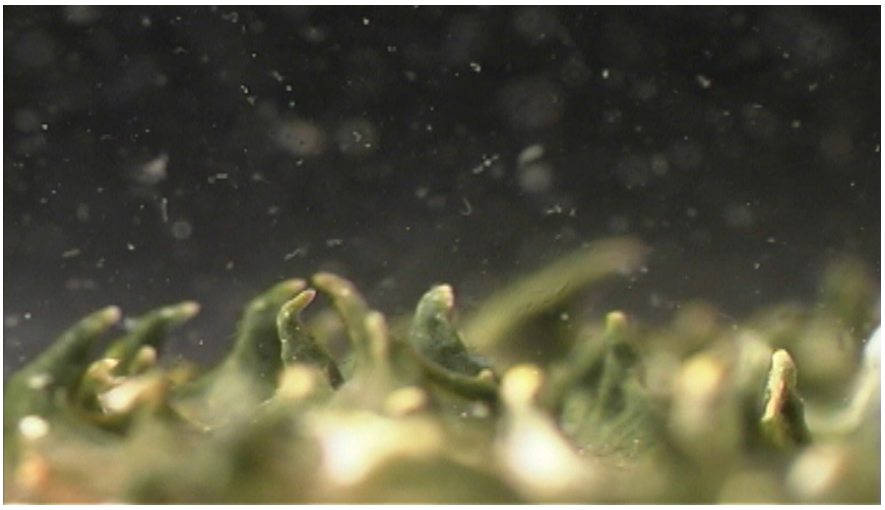
Our journey through a microbial mat has revealed how quickly life can change in just a few tiny millimeters – from photosynthetic algae at the surface, to sulfur munching bacteria just a hair away. These very simple forms of life are what exobiologists will be looking for when robot explorers are sent to Mars and other planets.

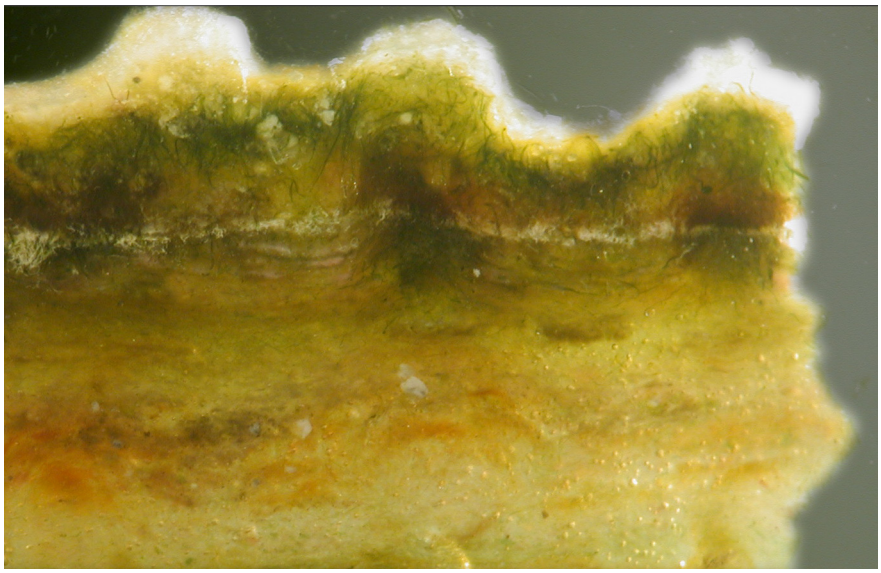
Stromatolites on Mars?

Mineral Layers that were Once Living Organisms

When probes seeking signs of life are sent to planets such as Mars, they are looking for simple living organisms like those found in a microbial mat community. If probes discover layered minerals, it would be powerful evidence that microbial life once thrived there.

As seen in this adventure microbial mat communities are made up of very thin layers of different microorganisms. The entire community is only 5 millimeters thick. The layered microbes produce various chemicals, which when trapped beneath new mats produce petrified mineral layers. Over vast stretches of time these stacks of layered minerals become fossilized and are known as **stromatolites**.





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